EVALUATION OF ELECTRONIC COMPUTER TECHNIQUES FOR HIGHWAY ENGINEERING CALCULATIONS.

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APRIL 1959

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THE UNIVERSITY OF ALBERTA

EVALUATION OF ELECTRONIC COMPUTER TECHNIQUES FOR HIGHWAY ENGINEERING CALCULATIONS

A DISSERTATION
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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SYNOPSIS

An electronic computer may be a very economical tool for solving highway engineering calculations when it is combined with an efficient computer staff.

Almost all state highway departments have an electronic computer to assist them in their engineering calculations. In Canada, Ontario is the only provincial highway department actively engaged in computer techniques although several other highway departments are seriously considering the use of these techniques.

Data is provided in this thesis to indicate that a direct saving of $145,000.00 per year may be realized by the use of a small electronic computer in the Saskatchewan Highway Department. Other less striking although equally important advantages over manual methods are:

a. Greater accuracy of calculation

b. More involved calculations possible

c. Capable of handling large masses of data quickly

d. Less supervisory time required and therefore more chance for advanced planning

e. Less routine calculations which tend to become boring and uninteresting.

A fully staffed computer center for the Saskatchewan Highway Department may be set up under the Design Branch utilizing approximately seven personnel.

A general survey of twenty different computers and a more detailed look at ten computers, shown on Fig. 3, would indicate that the choice of a computer for the Saskatchewan Highway Department would be made from either IBM 650, Bendix G-15-D and the Royal McBee's LGP-30. The final choice will rest between Bendix G-15-D and Royal McBee's LGP-30 which are both low priced computers renting for approximately $1,500.00 per month.

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A. PURPOSE

The main purpose behind the preparation of this thesis was to study the many implications involved and to determine whether or not it is practical for a highway department such as Saskatchewan to utilize electronic computer techniques. If it could be shown that it is practical, then the second problem was to determine the best method by which the electronic computer techniques might be integrated into the present highway organization.

B. DESCRIPTION OF COMPUTER

1. Analog vs. Digital

A computer is a device which has been devised to perform a series of calculations according to a set of instructions. The analog computer is a machine built to calculate one particular type of problem and is therefore not applicable for serious consideration by a highway department having a large variety of problems to solve. The analog computer performs calculations by a process of measuring (usually electrical impulses) and is characteristically fast, inaccurate and very specialized in

comparison to a digital computer. The digital computer performs these calculations by a process of counting and is slower but much more accurate than the analog computer. It is so flexible in use, it is capable of performing almost any type of calculation imaginable. The type of calculation which a digital computer can perform is limited only by the ingenuity of the men preparing the programs.

2. The Primary Function of a Digital Computer

A digital computer is nothing more than an ultra-high speed adding machine, which is capable of performing all the arithmetic operations such as addition, subtraction, multiplication and division, upon a set of basic data and according to a system of basic rules which have been previously prepared for this particular type of problem. By combining the basic arithmetic operations and storing the intermediate results it is possible for a computer to perform any mathematical calculation. Economics, however, may enter into the decision of whether or not to use a computer for a particular problem where the time required to prepare the set of rules for the computer may be exorbantly long as compared to the time of actual calculation.

Computers have been referred to as "rapid idiots". To refer to them as "brains" is a mistake, since the computer is only a useful tool in the hands of an efficient operator.

A computer is primarily made up of five distinct functions. These functions are:

a. Input

b. Memory

c. Arithmetic

d. Control

e. Output

a. Input

The input to a computer may be in several forms:

(i) Manual operation of a keyboard.

(ii) Punched paper tape.

(iii) Punched cards.

(iv) Magnetic tape.

These devices are used as the link between "man" and "computer". The input may be in the form of instructions for the computer to follow or it may be numerical data, on which calculations are to be performed. In either case, the input median

is interpreted by the computer and transferred to the memory in a form that can be utilized during calculation. For example, the input data will probably be in decimal notation. That is, we are accustomed to working in a number system to the base ten. Most computers, on the other hand, do their internal calculations in a binary form of arithmetic, in order to simplify the internal circuitry. In binary arithmetic there are only two symbols used, which may be easily represented by either an on or an off position of an electrical switch. In decimal arithmetic, it is necessary to represent ten distinct symbols. This use of binary arithmetic by the computer does not cause any great concern to the operator, as all conversions are automatically performed.

b. Memory

In discussing "memory" perhaps it would be wise to change the generally accepted word to one which is a little less misleading. When you think of "memory" you associate it with "the power of thought". The memory of a computer does not have that facility, but merely has the capacity for storage of information, thus "storage" is a more exact term to use than "memory". There are several types of storage devices presently being used by manufacturers of computers. The most common type of storage is a magnetic drum, in which the numbers are represented by magnetic

spots. Other types of storage available include:

- (i) Magnetic cores.
- (ii) Magnetic discs.
- (iii) Mercury delay storage.
- (iv) Vacuum tubes.
- (v) Acoustic delay lines.

c. Arithmetic

The arithmetic section of the computer does the work which its name implies. It performs the operation on the figures in storage, according to a set of instructions, called a program.

d. Control

The control section co-ordinates the activities of the other sections in order to perform the program and arrive at the result. It is through the control section that instructions may be transferred to or from storage.

e. Output

Output is simply the reverse of input. It involves the printing out of the answers, or any intermediate or initial

data, in a readable form.

3. Programming

Some mention has been made in the previous discussion of programming. Programming is the process of preparing detailed instructions for the computer so that it may perform a series of operations to arrive at a desired solution. Each different type of problem must have a separate list of coded instructions giving the exact method of solution before any calculation can begin. This programming time may represent a large percentage of the computer cost where there are a great variety of problems to be solved. The number of programmers required for a computer installation will vary a great deal depending on the particular application. In most highway departments the number of programmers would run between 1/4 and 1/5 of the total computer staff. Programming is by far the most difficult portion of a computer application. For anyone who is particularly interested in this aspect of computers the author would like to recommend a book entitled "Digital Computer Programming" by D.D. McCracken. It would be virtually impossible to discuss this topic in any detail in this thesis.

As time progresses it is found that less and less time is required for programming of a particular problem. This is due to several reasons:

a. There are many existing programs which have been prepared and are available, free of charge, for some of the more common problems.

b. As programmers become more acquainted with their jobs they become more efficient at programming.

c. Techniques are available and in the process of development, by which much simpler programming may be carried out, using everyday language and leaving much of the detailed coding to the computer.

In this same line are routines which will convert a program for one computer to a program for a different make of computer. In the past this process was so involved that it was quite often quicker to start from the beginning and ignore the original program when preparing a problem for a new make of computer.

In the Saskatchewan Highway Department it should be possible to keep the programming cost quite low as the

primary work will be in earthwork quantity calculation where existing programs are available. No computer operation however, may exist without at least one programmer to keep the operation at the peak of efficiency.

4. Range of Application

Computers may be used in many types of problems where speed and the accuracy of computation are important items. In even the smaller computers speeds are in the order of one hundred operations per second; thus, there may be direct economic saving in manpower due to putting routine calculations on a machine. Of far greater importance and of more significance, are the changes in procedure that can be adopted by the use of this tool. Studies which were at one time beyond the scope of possible solution due to the time required for computation may be performed. Designs that were not the most economical due to the shortage of time to perform the manual calculations can now be redone many times to arrive at the ultimate in economy. These points will be discussed in greater detail under the application of the computer to the specific needs of the highway department.

C. EXPERIENCE WITH COMPUTERS IN HIGHWAY DEPARTMENTS IN UNITED STATES AND CANADA

1. Source of Data

A questionnaire which is contained in the bibliography was sent to each of the provincial and state highway departments in order to obtain an inventory of the present practices in the highway field. A summarization of the results from these questionnaires is contained in Fig. I. Correspondence was carried on with many of the highway departments and the Bureau of Public Roads on other special problems connected with computer application. Further information was obtained by personal contact with men running the computer departments in North Dakota, Illinois, Michigan and highway consulting firms.

2. Number of Computers

Out of the forty-nine highway departments in the United States thirty-seven are using electronic computers for engineering calculations. Four of the remaining highway departments have computers on order. Four other state highway departments which are not using these techniques are seriously considering doing so. Three states feel they have no need for a computer. No information was received from one state.

3. Types of Computers

Out of the forty-two highway departments which use electronic computers twenty-six use I.B.M.'s 650, two use I.B.M.'s 604, one uses an I.B.M. 610, one uses an I.B.M. 602A, one uses part time on an I.B.M. 705, one uses part time on a Univac I, eight use a Univac 120, two use a Bendix G-15-D and one uses a Royal McBee LGP-30.

4. Problems being Solved

A list is included in the appendix of some of the highway engineering problems being solved on electronic computers. There would not appear to be any phase of highway engineering which has not been programmed for the computer and yet still more are being prepared day by day. The most common problem for the computer in highway engineering is the calculation of design earthwork quantities. Ninety-two percent of the highway departments with computers utilize this program. Fifty-one percent utilize the computer to calculate final earthwork quantities. Sixty-four percent have traffic and planning programs in use on the computer. A great deal of progress has been made in integrating the electronic computer with photogrammetric methods. The state highway department of Ohio and the Massachusetts Institute of Technology have pioneered work in this field.

5. Apparent Range of Application Depending on Size of Department

A study of Fig. 2 will indicate the apparent range of highway mileage and highway expenditure which is required to support an electronic computer. In order for this chart to mean anything as far as a department such as Saskatchewan obtaining a computer is concerned, we must accept the following statements:

a. The primary factors that determine whether electronic computer techniques are feasible in a highway department are:

(i) The amount of time being spent on highway construction.

(ii) The total number of miles being built each year.

b. The departments which are using computers continue using them becuase they are found to be economical as compared to manual methods.

c. State highway departments and provincial highway departments of the same size are comparable.

If these statements can be accepted then it necessarily follows from the graph that Saskatchewan, Alberta, Manitoba, British Columbia and Quebec Highway Departments should be utilizing a small electronic computer to assist them in engineering calculations.

6. Staff Requirements

The size of the staff being used to handle the computer section in highway departments in the United States and Canada varies from three to thirty-two. The average staff for the I.B.M. 650 is fifteen, for the Univac 120 is twelve, and for the Bendix G-15-D is five. The Bendix G-15-D has a smaller staff requirement because it is not being used for accounting work. The I.B.M. 650 and the Univac 120 are punched card machines and therefore require staff to handle the auxiliary punch card equipment. It has been noted that the average staff of the Bendix G-15-D is five, however, both Illinois and Michigan Highway Departments, from which this average was obtained, have additional personnel who do programming on a part time basis. The average staff for the Bendix G-15-D in this type of work probably is closer to seven.

Michigan has a typical staff for a small tape input computer. It consists of one director, two programmers, one machine operator and two key-punch operators.

7. Cost for Computer Application

On Fig. I will be noted a column headed "Cost per Mile" for design earthwork quantities. The figures listed under this heading represent the estimated average costs which

the various departments experience for the calculation of one mile of design earthwork quantities for a two-lane highway, carried out on a electronic computer. The average of these figures equals $65.18 per mile excluding New Mexico since that state has only carried out computer applications on selected projects for a consulting firm. The cost which this state has submitted does not represent an average figure and therefore has been ignored in this calculation. In a similar manner, the average cost of final pay quantity calculations, by computer techniques, equals $33.90 per mile. The total average cost for the calculation of earthwork design and final pay quantities for a mile of two-lane highway equals $65.18 plus $33.90 is equal to $99.08. The average number of sections per mile for these same departments equals 97; the average number of points per section equals 15.9. In Saskatchewan the average number of sections per mile equals 65. The average number of points per section equals 12. The cost of computer application is almost directly proportional to the number of points per mile; therefore, the expected cost of computer application for Saskatchewan is equal to $99.08 x 65/97 x 12/15.9 = $50.00 per mile for calculation of design and final pay quantities.

D. EXPECTED TIME ALLOTMENT FOR A SMALL COMPUTER BY SASKATCHEWAN DEPARTMENT OF HIGHWAYS

Discussing this matter the Royal McBee's LGP-30 electronic computer shall be used, since it would appear to be suitable for the department's needs.

1. Design

The Design Branch will be the largest user of the computer, utilizing 6.0 months of machine time. This time estimate is based on using the computer 200 hours per month (see Fig. 3). This 6.0 month figure is further broken down into 5.8 months for design earthwork calculations and 0.2 months for miscellaneous design problems. The 5.8 month figure was arrived at by considering the design of 500 miles per year. It was assumed that 90% of this work was passed through the computer. The remaining 10% of the design would involve special problems such as urban cross-sections and interchange areas, for which adequate programs would probably not be available for computer application. A figure of 65 cross-sections per mile was used to represent the average conditions.

The time required to process each section of design earthwork computation is slightly more difficult to estimate. Assistance on this feature was received from many State Highway Departments, Technical Computer Journals and from Mr. Radzikowski of the Bureau of Public Roads. The State Highway Department of North Dakota uses an LGP-30. Enough time was spent with Mr. Albers of that department to obtain a very close estimate on the time required to process a section of design earthwork for Saskatchewan. The program which North Dakota uses is very close to the one which may be needed for Saskatchewan. Some parts of this program may be used directly. This complete program required 60 seconds per section for a complete run, including the input and out put time. This time does not, however, include preparation of tapes, but since this is an off-line process, it does not in any way affect the time of operation on the computer, but merely affects the number of key-punch operators required. The first step in the process would be the calculation of quantities for a trial balance, using an approximate method. It is estimated that 12 seconds per section would be required. This 12 seconds was arrived at by comparing the speed of the LGP-30 with that of the Bendix G-15-D for which a simplified program has already been prepared. This existing program takes approximately 10 seconds

per section. It is expected that an average of two additional detailed runs will be required before the final grade line is arrived at. This assumption of an average of three trials is a little higher than is presently being exercised. With a computer, however, more trials would be attempted, due to the speed and facility of use. This increased number of trials would show up as a more economical design.

The collection and summarization of all these factors is shown on Fig. 3, in which a total time is arrived at for design and final pay earthwork computation.

2. Construction

The proposed use of the computer by the Construction Branch is indicated on Fig. 3 under "Earthwork Calculations". It is assumed that the mileage of final pay quantity calculation done on the computer will be the same as that processed by the computer for design. That is, 90% of the total 500 miles built, would be processed through the computer. The times for processing were arrived at by correspondence with officials of the State Highway Departments, who are using similar programs on comparable machines. A figure of

0.6 months has been arrived at as the time required to process this final earthwork data.

There are other problems which could easily be programmed for use by the Construction Branch. One of the most common, presently is use, is one which calculates and records bid items. These additional problems have not been considered in the present analysis but would have the effect of reducing the cost of computation on earthwork. Earthwork quantity calculation is the primary guage for comparing computers. Any additional problems which were solved on the computer would reduce the waste time and make the operation more economical. The original cost which is shown will be reduced as the computer becomes more familiar to the various branches.

3. Planning

The Planning Branch has been newly organized. This branch is not burdened by outmoded techniques which they are leery about giving up. Instead, they are organizing their work in a logical and efficient manner which recognizes the need for modern techniques in order to get the most information

at the least cost. Mr. R. Genereux, Planning Engineer and Mr. W. McLaughlin, Traffic Engineer are both convinced that electronic computers are a must for the work which they plan to do in the next few years.

Some time has been spent with the Planning Branch in an attempt to estimate time requirements which they might have on a computer during one year. The following estimate was arrived at, based on a small computer such as the LGP-30.

a. The calculation of average annual daily traffic data for 865 separate count positions	42 hours
b. (i) For the computation of variance in daily traffic flow by the day and by the hour	195 hours
(ii) Traffic assignment problems based on O.D. studies	
(iii) Miscellaneous economic studies	
Total time required for Planning Branch	237 hours

In making the economic analysis a figure of 200 hours or one month was used in order to eliminate any chance

of over-estimating the time required. Should extra time be required by this branch it could be made available from the 1.4 months still unassigned.

4. Surveys

The use of the computer by the Surveys Branch will depend to a large extent on the availability of the machine. Many of their traverse calculations would certainly be adaptable to the computer, but since the present practice is for the survey crew to calculate this data after hours, it is hard to justify any saving in money by using a computer. These calculations are performed in the field following each day's work and, therefore, the time advantage of the computer would, no doubt, be lost due to the time required for mail to go back and forth from the computer center. For involved traverses the computer would certainly be practical. In certain rush jobs the traverse information would be telephoned in to the computer center and the answers telephoned or telegraphed back. It would appear though that the biggest use of the computer by the Surveys Branch would be in checking of plans. It is here, where a large volume of work may be processed at one time, and where the time element

between sending in the data and receiving answers is not such an important item, that the computer would have its largest application.

There has been allowed for the Surveys Branch only 0.1 months or approximately three days of computer time. This branch could probably utilize more time on the computer than this, but where the plan checking is being done in one building and the computer is across the city, there is a reluctance on the part of men doing the work to be bothered with the computer.

5. Bridge

There are many problems in the Bridge Branch which may effectively utilize electronic computer techniques. The problem has been discussed with Mr. Pierce, the Bridge Engineer. Together we have arrived at an expected time requirement on the computer by this branch of 0.4 months per year or about nine working days. It was further suggested that the programmer (as shown on the planning chart) come from the Bridge Branch to work with the computer on a part-time basis. It is realized that there will be a great deal of programming to do in this field. An engineer familiar with the bridge problems is necessary to assist in

writing these programs.

Structural design work is one of the most important uses to which computers have been placed. Illinois Department of Highways illustrates a time saving, over manual methods, in this type of work of around 50;1.

The following problems which may be adapted to the computer are of particular interest to Mr. Pierce:

a. Design of a retaining wall.
b. Abutment design.
c. Influence lines - continuous girder bridge - seven spans.
d. Swedish slip circle - method of embankment stability analysis.

In this branch as in others, the use of the computer would be increased if it were located in the same building as the branch. Communication time is a problem on short computation. The 9 day estimate shown is based on operation in the present buildings. With a common building this time estimate would need to be raised, due to the increased ease in using the computer.

6. Materials

The use of the computer by this branch is expected to be limited to about 3 days per year. This work will consist of utilization of the Swedish Slip Circle program for embankment stability analysis and the statistical analysis of factors controlling the design of pavements. Mr. B.C. Laws, Supervising Soils Engineer, is presently engaged in a testing program to obtain data to aid in the analysis of existing pavements. This data will be collected and tabulated. Statistical analysis of the data will be made in an attempt to evaluate the number and size of the controlling factors in order to arrive at the best pavement evaluation formula, based on the most significant of these factors. If the program is carried out to its expected completion, then the computer in conjunction with punch card equipment would be an essential item in order to evaluate the mass of data which would be collected.

The A.A.S.H.O. are utilizing a G-15-D in conjunction with a Univac computer to analyze and evaluate the date collected in connection with the road test being conducted at Ottawa, Illinois.

Three days would not be enough time if the testing program which Mr. Laws has is carried forward to completion. If the need arose the computer would be operated for short periods after hours at little extra cost.

7. Program Checking

In looking at Fig. 3 it will be noticed that 1.7 months has been allowed per year for program checking. This may appear to be excessive considering that the main purpose of the computer is to calculate earthwork design and final pay earthwork quantities which have existing programs available. It is found however, that regardless of what programs are used, there always appears to be some improvements which can be made in these programs to make them more adaptable to local conditions and to improve the efficiency of the computation. United States highway experience would indicate that it is a mistake to hope that you can operate on a set of "canned" programs without periodic modifications. Another factor which is ever present is the development of new programs for the computer in order that new problems may be processed. All of these new programs, or

modifications of existing ones, require time on the computer during which the program is tested for correctness. The figure of 1.7 months was arrived at after analysing Saskatchewan's particular problems and discussing the matter with State Highway officials in the computer field.

8. Repair

Repair represents the "down-time" experienced by the computer. It was not possible to obtain this figure for the LGP-30 in the highway work since it has not been in operation long enough in this field. "Down-time" records have been kept however, for other installations of the LGP-30. The records would indicate a value of between 6% and 7%. This would give a "down-time" of approximately 0.8 months.

E. COMPARISON OF COMPUTER VS MANUAL TECHNIQUES

1. General

A computer is a tool which may be used to advantage under certain conditions when guided by a carefully prepared program. When comparing computer vs manual methods it must be remembered that the discussion is more concerned with the degree

of manual requirements rather than the absolute comparison. The computer techniques are still probably 30% manual by the time the programming, machine operation and key-punching is considered.

In making the detailed comparison between computer and manual techniques, earthwork calculation shall be the primary item for comparison. This is the largest program which is used by highway departments and the one for which the most information is available on items of comparison. Other programs will be touched on only.

2. Steps in Earthwork Quantity Calculations

a. Manual

(i) The present steps required in the calculation of design earthwork quantities by manual methods in Saskatchewan are:

(1) The field notes are checked and the elevations calculated for center line and the edge of right-of-way.

(2) From these elevations and the remaining rod readings the preliminary cross-sections are plotted.

(3) The preliminary and design grade line profiles are drawn at the center and edge of right-of way on the plan profile sheets.

(4) The design center line and ditch grade elevations are calculated.

(5) With these elevations and the correct template or design cross-section elements, the design section is drawn over the preliminary.

(6) The resulting areas between the two sections are calculated (usually with the aid of a planimeter.)

(7) These areas are transferred to the quantity sheets where the volumes are calculated.

(8) These cut and adjusted fill volumes are then added to come up with a mass diagram tape.

(9) The ordinates for the mass diagram are then plotted and the resulting overhaul is calculated.

(ii) The steps in the calculation of final pay quantities are:

(1) The field notes are checked and the elevations

are calculated for the center line and at the edge of the right-of-way.

(2) From these elevations and the remaining rod readings the final cross-sections are drawn over the preliminary sections.

(3) These sections are checked for accuracy of plotting and for accuracy of end closures.

(4) The resulting areas are calculated. These areas are usually gone over two or three times, until a good check is obtained. Then some other person will check the work.

(5) These areas are then transferred to a quantity sheet where the volumes are calculated. All of these steps must be double-checked.

(6) The cut and fill volumes are added to come up with a mass diagram tape.

(7) The ordinates for the mass diagram tape are plotted and the resulting overhaul is calculated and adjusted for the correct shrinkage factor.

b. Computer

For the computer application in the calculation of earthwork design quantities the following steps can be eliminated or transferred from the manual methods to the computer. (Steps No. (2), (4), (5), (6), (7), (8) and (9)). For final quantities the following steps would be affected. (Steps No. (2), (3), (4), (5), (6) and (7)). Steps to be followed in the computer application are:

(i) The plan profile sheets would need to be drawn with almost the same volume of information required on them as at present. There is perhaps some question as to whether it would be necessary to include ditch and center line elevations on these sheets, but they might be included for convenience of field use. Any design information which is calculated by or supplied to the computer can be printed out in a summary sheet so as to give all the pertinent design details in a convenient form.

(ii) Field notes would probably be reduced by manual methods to give the elevation at center line and at

the edge of the right-of-way, in order to give the instrumentman a chance to check his work before the notes are sent to the computer center for calculation. These elevations would then be plotted on the plan-profile sheets to give a profile of the existing terrain.

(iii) A copy of the field notes would be sent to the computer center along with the design template and grade line information.

(iv) From a copy of the field notes and design information the key punch operator would prepare the tapes for input into the computer.

(v) Assuming all information has been supplied correctly and that the appropriate program is in memory, then the computer will do all the computation necessary to come up with the mass diagram tape, slope stake co-ordinates and other additional information desired.

3. Costs for Earthwork Calculations

a. Manual

To arrive at an accurate figure for the cost of earthwork computation is no easy problem. Costs will vary depending on the topography, class of road, care exercised and speed of design crew. The Division Engineers and other Design Engineers were invaluable in assisting the author to arrive at a representative figure for the Saskatchewan Highway Department on actual costs being incurred.

(i) Unit Costs

(1) Engineer

(a)	Wages = $400/22	= $18.20 per day
(b)	Sustenance (based on assumption that 50% of the work is being done while sustenance is being paid = 5/2	= $ 2.50 per day
(c)	Total	= $20.70 per day

(2) Instrumentman

(a) Wages = $10.60 per day
(b) Sustenance = $ 2.50 per day
(c) Total = $13.10 per day

(3) Rodman or Junior Instrumentman

(a) Wages = $ 8.55 per day
(b) Sustenance = $ 2.50 per day
(c) Total = $11.05 per day

(ii) Design Earthwork Calculations

(1) Plotting original cross-section (one rodman at two miles per day):

Cost per mile = $\frac{\$11.05}{2}$ = \$ 5.52 per mile

(2) Design includes:

(a) Drawing design cross-sections.
(b) Planimetering and calculation of quantities.
(c) Time spent redoing sections where the earth does not balance.

(3) This does not include setting the grade line but does include the time spent on calculation of grades.

(4) The rate of design equals 0.5 miles per day for a three-man crew of one instrumentman and two rodmen. An engineer has previously set the grade line and decided on all the design details peculiar to the job. His time is not included in the estimate, since the computer will not substantially reduce this portion of the work. The time normally spent on supervision of a design crew is a saving to the engineer under a computer application. It will not be considered in this analysis, but will be discussed at a later part.

(5) Cost per mile $= \frac{2 \times \$11.05 + \$13.10}{.5}$

$$= \frac{\$35.20}{.5} \qquad = \$\ 70.40$$

(6) Total cost of design by manual methods $= \$70.40 + \$5.52 \qquad = \$\ 75.92$

(iii) Final Earthwork Calculation

Preparing finals using the same crew:

(1) Cost of preparing finals at

3/4 mile per day = $35.20 x $\frac{4}{3}$ = $ 47.00

(2) Checking finals at two miles per day with one engineer and one instrumentman =

$\frac{\$20.70 + \$13.10}{2} = \frac{\$33.80}{2}$ = $ 16.90

(3) Total cost of calculating finals by manual methods = $ 63.90

(iv) Total Costs

Total cost of design and finals for one mile of highway by manual methods

= $75.92 + $63.90 = $139.82

(say) $140.00

b. Computer

For the purpose of this cost comparison the LGP-30 shall be assumed on a monthly lease basis. The reasons behind this choice shall be described later.

(i) Basic Units

(1) LGP-30 and Flexowriter = $1250.00

(2) Subtotal = $1250.00 per month

(ii) Auxiliary Equipment

(1) 2½ Flexowriter @ $175 = $ 425.00

(2) Photoelectric reader Model 200 = $ 225.00

(3) Subtotal = $ 650.00 per month

(iii) Incidental Expenses

(1) Mail = $ 40.00

(2) Supplies = $ 200.00

(3) Subtotal = $ 240.00 per month

(iv) Personnel

(1) Key punch operator 4 @ $220 = $ 880.00

(2) Chief key punch operator = $ 300.00

(3) Programmer and coder = $ 400.00

(4) Computer planning engineer = $ 600.00

(5) Subtotal = $2180.00 per month

(v) Office

(1) Minimum space requirement for basic unit:

100 sq. ft. @ $.20 = $ 20.00

(2) Power:

1.5 kw x 154 hr./mo. x $.03 kwh. = $ 7.00

(3) Cooling fans = $ 3.00

(4) Subtotal = $ 30.00 per month

(vi) Additional programming required:

$1500 for a period of 48 mo. = $\frac{\$1500}{48}$ = $ 30.00

(vii) The total cost per month for computer application = $4380.00 per month

(viii) Fig. 3 indicates how the time on the computer may be expected to be alloted to

the various branches. The earthwork calculations represent 67% of the time.

(ix) The cost per mile for design and final earthwork quantity calculations:

$$\frac{67\% \text{ x } \$4380/\text{mo. x } 12 \text{ mo./yr.}}{500 \text{ mi./yr. x } 90\%} = \$78.00 \text{ per mile}$$

4. Utilization of Presently Employed Personnel

A very important question, and one which is rather difficult to answer is "What is going to happen to the personnel who are presently doing the work which will later be done by the computer?". With the engineers and engineering assistants the question is easily answered for they will turn their attention to details in design which are not applicable to the computer and which represent large expenditures of money. Since the computer is quite reliable and very little supervision is required in the large quantity of routine calculations which may be carried out on the computer. The engineer may thus

direct his time to more specialized problems which at present are not receiving the attention they deserve. This increase in attention to these specialized problems will precipitate work for the men presently doing the routine calculations. Thus it can be seen that the computer is not expected to replace large quantities of men, but rather to cause a diversion of their attention to more specialized problems. This argument may sound a bit like a pipe dream but in reality this is what is happening in the United States. The computer has not caused reduction in staff but rather an increase in accuracy and thoroughness of the engineering studies being carried out; thus resulting in more economical highways.

5. Reduction is Construction Costs

Most of the design carried out on our highways is done by a group of engineers that are under pressure and are racing against time. The shortage of engineers has resulted in designs being done hastily with insufficient time being placed on details. Mistakes have been made and the most economical grade line to fit a certain type of topography

has not always resulted. The exact savings to be expected due to a reduction in the work load on the engineers is difficult to determine. A design carried out with greater time for details is certain to bring about savings in drainage structures, force account and earthwork quantities. It is not unusual to be able to save $100.00 on a ten mile stretch of highway simply by a little closer design, which is possible where more drainage information is available.

Ohio uses a combination of aerial photography and electronic computers in the calculation of their earthwork and final pay quantities. They estimate a saving of 3% to 5% in earthwork volumes in moderate rolling to flat topography due to the possibility of being able to check through several possible routes and grade lines. In rough topography, they estimate a saving as high as 10%. Here in Saskatchewan our grade lines are fixed largely by height above water table, or average height above natural ground. Despite this, the possibility of being able to try several grade lines would effect a saving in earthwork, which might

average around 2%. If this 2% saving in earthwork can be realized, it would result in a saving of about .02 x 30,000 x .20 = $120.00 per mile. Thus, it can be seen that it does not take much of a saving in construction cost before a computer has paid for itself on this item alone.

6. Speeding of Payments to Contractors

Another indirect benefit from the use of a computer which must not be passed over too quickly is that of quicker payments to the contractors. Many hard feelings, and excessive financial burdens, result when a season or final payment cannot be made, because the final calculations have not been done. A high speed electronic computer will not eliminate this problem, but it will certainly help to relieve it. Contractors take the slowness of payment into consideration when they bid on a job. It shows up as perhaps an extra ½¢ per cubic yard on the common excavation price, which would amount to approximately $150.00 per mile.

7. Accuracy

All engineering calculations whether done by manual or electronic computer techniques have a certain limit to their accuracy. Earthwork calculations can be no more accurate than the field notes. There is also a certain systematic error in the average end area method of calculation. These errors are expected as unavoidable limits to the accuracy of earthwork calculations. A computer application cannot eliminate these errors. There are, however, certain types of errors introduced into manual methods due to inaccuracies in plotting, planimetering of the areas and computation of the volumes, etc. The electronic computer will produce results, the accuracy of which is limited only by the accuracy of the input data and the method of computation employed. Because of this accuracy of computer techniques, these methods have been accepted and appraised by national contractors' organizations in the United States.

8. Diversified Problems

Earthwork calculation is the base load for the computer installation in most highway departments. Without this base load many of the departments could not afford a machine. Earthwork computations done on the computer are certainly a very advantageous procedure over manual methods, but they are one of the least efficient as far as computer operation is concerned. Theodore F. Morf, Engineer of Research and Planning of Illinois Division of Highways, has this to say in regard to their computer application which is making use of a Bendix G-15-D: "We have no exact figure on the cost of electronic computation, but consider that the ratio of efficiency of the computer, to the engineer, in this type of work (he is referring to earthwork calculations) is about 20 to 1. I might add that we believe in the structural field the ratio goes to a range of about 50 to 1, for geometric problems to a range of about 100 to 1. These ratios are on a man hour basis rather than a cost basis." The total cost of the completely staffed computer application for the Bendix G-15-D would run

around \$4,800.00 a month. This represents a cost of $\frac{\$4,800.00}{400}$ = 12 engineers. Thus the ratio of cost of computer application to manual methods would run around 1 to 1.7 for earthwork calculations. One to 4.2 in structural field and 1 to 8.3 in the geometric problems.

It can easily be seen that earthwork is the least of the savings which are to be expected from the electronic computer techniques. The other problems, although small in volume, are large in savings. These types of problems will grow in volume as more and more programs are written and the computer becomes a more common tool in the department. It will take time before these methods are utilized to their full extent for these specialized problems. They have, therefore, received only a meagre representation in the cost analysis. As time passes, these diversified problems will have a substantial effect on decreasing the cost of earthwork computation.

One of the greatest savings to be expected from computers will come from a new concept in the approach to problems.

At present we are thinking of computers as tools which may duplicate manual methods. The computer, however, has a much greater potential in arriving at a solution along lines which have not yet been attempted. A whole new science is developing around computer techniques and mathematics for computers. For example, a trial-and-error method may be handled in a computer to solve almost any mathematical equation to any desired degree of accuracy. Quite often these trial-and-error methods are quicker than solving a series of simultaneous equations and yet they are techniques which are very seldom used in manual methods. A complex integral for which no known solution is available can often be handled quite simply in a computer by trial-and-error methods or summation of smaller segments. Many problems too complex to even attempt by manual methods are now being done on computers. Many of our traffic problems fall in this category. If they are left unsolved they may result in millions of dollars being expended by the travelling public in additional mileage. Traffic simulation studies may now be economically made to study the effect of certain control devices on traffic. The cost of

the study is small in comparison to the cost of a mistake.

9. Summary of Comparison

It has been shown that an electronic computer may effect a direct saving of $62.00 per mile in the calculation of design and final earthwork pay quantities. An additional $120.00 per mile due to the reduction in earthwork quantities may be realized as a result of the closer design. It is expected that an additional $150.00 per mile be realized by the reduction on bid prices due to the speeding up of contractors' estimates. There will be additional economic savings in fields other than earthwork quantity calculations. These savings are not considered in this estimate. The total direct economic saving due to the use of a small computer as compared to manual methods is equal to $332.00 per mile or $332.00 x 500 mi. x 90% = $145,000.00 per year for the Saskatchewan Department of Highways. There are many other indirect advantages to using these modern techniques:

a. Greater accuracy of calculation.

b. More involved calculations possible.

c. Capable of handling large masses of date quickly.

d. Less supervisory time required and therefore more chance for advanced planning.

e. Less routine calculations which tend to become boring and uninteresting.

F. EFFECT OF COMPUTER ON DEPARTMENT ROUTINE

1. Standardization

Like any new device, an electronic computer system is going to result in changes within the department. The big change is standardization of methods. In order for any computer to carry out calculations every step must be outlined in detail. The exact procedure to be followed must be arrived at by the experts in each individual field. These procedures are then supplied to the machine which will follow the instructions given to it exactly. The computer cannot exercise any reasoning power, but it can be programmed to react a definite way when a certain given condition exists. For example, when the

last shots on finals do not fall at the same elevation as the prelim, the engineer doing the final will probably exercise his judgment to decide whether that place should be re-checked in the field or if some adjustment can be made in the office, such as assuming the prelim is right in cutting off the section at the point where the prelim and finals cross. Perhaps he prefers to assume that the final is right and adjust the prelim to correspond. There are many such assumptions that can be made. A computer can exercise the same ability of choice, which it will make consistently, providing the "how" and the "why" are provided. On any one set of finals no two engineers will make the same adjustments, nor is the same engineer liable to make exactly identical adjustments on a second run through the same problem. On the other hand a computer will exercise consistent judgment every time, the accuracy of which is limited only by the program on which it is working.

2. Place of Installation

It is wise to set up the computer in an office by itself, but one which is readily accessible to those departments

which will use it. Smaller models of computers require no special wiring or air conditioning of the building. The weight of the smaller computers run around 1000 lbs. and therefore can be handled on available office space with no extra bracing or reinforcing of the floor.

3. Breaking into the Computer Field

It is advisable to break into the computer field rather slowly by using consulting firms during the transition period. Approximately 100 miles of design and finals could be sent to one of these firms for computation. This work would be picked from all over the province, with probably one section taken from each of the divisions.

Price quotations have been received from three consulting firms who do highway engineering work with a computer. The figure vary slightly, but as an example, C.C. Parker, Whittaker and Company Limited of Calgary, have made the following quotation, based on a guarantee of 400 miles of approximately 65 sections per mile. They will process, design earthwork

based on approximately three trial grade lines, at a cost of $1.32 per section for complete design, or $86.00 per mile. They will process final pay quantities at a cost of $.90 per section, or $58.00 per mile. It would not be economical to handle any great amount of our computation in this manner, but it does provide an opportunity to break into the computer field and train personnel without actually paying rental on a computer which would require some familiarization before being efficiently utilized. As the understanding of and familiarization with computer techniques increases, the department could begin preparing its own input tapes for the computer. If all the tapes were punched they could probably rent time on a small computer for about $25.00 per hour. The final step would be the leasing of the computer and the department doing all its own work. This break-in period could be effected in about six months.

4. Effect on Field Personnel

As previously explained the actual reduction in staff, due to electronic computer techniques, will probably not be too great. Field notes will be taken in primarily the same manner as is now being carried out, though certain precautions are required. The notes will be transcribed to tape by a typist who will probably only have a limited knowledge of field practices. If notes must be referred back to the field for interpretation than much of the advantage in time saving is lost.

5. Precuations in Note Keeping

a. The field notes should follow a standard form.

b. The notes must be clear and well spaced.

c. There must be no ambiguity as to:

- (i) What the figures are;
- (ii) What station they refer to;
- (iii) What H.I. to use, etc.

d. In the interest of standardization all rod readings, above the H.I., should be referred to as negative

values. Perhaps they could be circled in red to stand out.

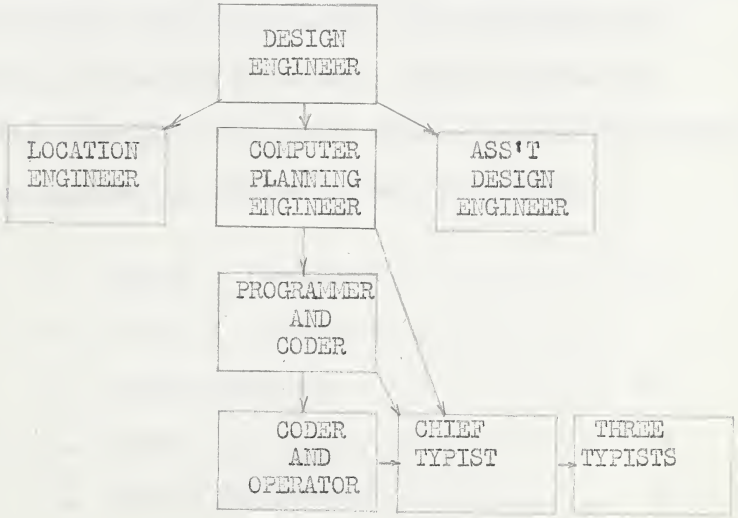
e. It will be necessary to carry out preliminary rod readings to the limits where a design cross-section might fall. This is particularly important when going through a slough area, where the tendency is for a rodman to be a little afraid of getting his feet wet. A guess at the proper rod reading and distance is better than nothing. Where the water is very deep, the computer can be programmed to approximate the missing rod readings. This approximation is not as good as can be made by the man actually doing the survey.

f. A new type of field note book is in the process of being developed. There are many advantages to a pad type form with carbons to give a duplicate copy. This pad could be used in conjunction with a clip board to give a firm back to write on and a loose leaf folder to contain the pages, when they are torn off the pad. A sample of the proposed form is shown. The type of paper which is used in this report is not representative of that which would be used for the pad. This method of

handling notes has many advantages, one of which being that it helps to standardize the methods of taking cross-section notes. It aids in keeping figures separate and therefore clean and easily understood. The duplicate copy idea is a safeguard against the loss of notes through the mail or by fire or theft.

G. ORGANIZATION OF COMPUTER CENTRE

1. Under What Branch of the Department Should the Computer Be Set Up?



Above is the sketch of the proposed set up for the Computer Division within the Saskatchewan Department of Highways. The first question which must be answered is "Should the Computer Division be set up as a separate service or should it fall under one of the existing branches?" Most of the computer sections in the State Highway Departments are set up as independent organizations which are responsible to no individual branch. In this way they claim to be able to give a fair and unbiased service to each of the branches. There would appear to be a definite advantage to this type of set up in a large department. In Saskatchewan the situation is somewhat different. First, consider the probable percentage of computer time to be used for solving various engineering problems in each department:

1.	Design)	(Earthwork)	54%
2.	Finals)	(Earthwork)	6%
3.	Program Checking		16%
4.	Bridge		4%
5.	Traffic Engineering		9%

6.	Survey	1%
7.	Incidental Design	2%
8.	Repair	7%
9.	Materials	1%
	Total	100%

The Design Branch will be by far the largest user with approximately 56% of computer time. Although it is planned that all earthwork design aside from actual calculation will be carried out in the field, still minor adjustments of grade for balancing can be carried out by competent design personnel in the computer centre if they are available. The calculation of final earthwork quantities should require no special attention above a sub-professional level once the program has been prepared. The priority of work will have to be worked out by the Computer Planning Engineer under advice from the Branch Heads. There is no apparent reason why the computer centre could not operate efficiently under the Design Branch.

2. Programming Needs

Upon looking at the lay out of the computer section it might appear at first glance to have too many programmers and coders. The author feels that this is required for the efficient operation of the computer centre. To optimize the existing programs and produce new ones for each of the branches specific needs is an involved and time consuming job. It is not unusual to spend three or four months on an existing design program simply to reduce the time of computation by thirty seconds per section. The time spent on this programming pays for itself many times over in a period of a few years.

Consider some of the conditions which North Dakota is experiencing in their computer center for the Highway Department. Dewey Albers was given the task of studying the possible application of electronic computers in that department. After approximately one year of study he came up with the recommendation to lease an LGP-30 for use by that department. This recommendation was approved. After proper

preparation he began working on an adaptation of the Illinois State Design Program for use in North Dakota. He began his work around the end of 1957 and by March of 1958 he had a program ready for checking and debugging. He spent several weeks at the Computer Centre in Chicago debugging his program. Further work was done on it until the middle of May when they obtained their computer at North Dakota. For the next two months they have been operating at low efficiency while they attempted to iron out further bugs in the program and improve the range of application in the design earthwork field. They presently have a staff of one programmer, one trainee for programming and one typist. The program which they have set up is one of the most complete in the Design Earthwork field that the author has seen. It is a general program made primarily to handle four-lane divided highways with independent grades and completely flexible design template possibilities. It automatically calculates the proper super-elevation and

and transition for simple and spiral horizontal curves. All of the output data which might be desired up to and including the mass diagram tape are printed out after a single run through the computer. At present this program takes approximately one minute and thirty seconds per section including input and output time. The input time is approximately 35 seconds which could be reduced to about five seconds by the use of a photo-electric reader. This leaves 60 seconds required for computation of one section. By careful optimizing of the program, this time could easily be reduced to 35 seconds per section. This optimizing might take as long as a year to carry out. Consider the economics of the situation. The cost of programmers' time equals 12 x 500 = $6,000.00. The cost of computer and allied equipment equals approximately $13.00 per hour. The time required for extra programming to pay for itself (assuming that the volume of work to take up the extra time saved is there) is equal to

$$\frac{\$6{,}000.00 \times 60}{13 \times 154 \times 25} = 7.2 \text{ months,}$$

It can be seen why the State Highway Departments are generally top heavy in programming staff. It is a straight case of economics. The computer is more efficient in almost every field of highway engineering calculation than manual methods. The more problems which can be prepared for computation (up to the ultimate capacity of the computer) then the cheaper these problems can be solved. Then, once the full capacity of the computer has been met it is usually economical to spend time improving and optimizing the existing programs in order to provide more time for further problems.

3. Duties of the Staff

a. Computer Planning Engineer

Once the computer section has been set up and the initial programs have been prepared and debugged, the actual running-through of the problems can be handled by semi-technical personnel. The main duties of the Computer

Planning Engineer should be that of organization, trouble shooting and preparing new programs. To write any program it is necessary either to know the problem completely or to obtain assistance on technical matters from those who are authorities on the subject. This involves either:

(i) Teaching one member of each branch computer techniques and letting him write his own programs, or;

(ii) Acquainting someone who has programming experience with the individual problems of each department.

The first method would theoretically appear to have definite advantages. This is, it is a smaller task to learn programming than it is to fully understand the solution to the calculation of any one department's problems. Practically though, such a scheme would fall flat on its face for the following reasons:

(i) There are very few men in any department that completely understand all the implications involved in that branch's individual problems.

(ii) This personnel would not have the time or the patience to sit down and spend weeks preparing a program for use on a computer.

(iii) They would need to be experts in their field and, as such, would not be utilizing their time to the maximum efficiency doing programming which they would naturally be awkward at. Probably the best arrangement would involve the use of an engineer who is reasonably well acquainted with the various highway engineering calculations. This engineer would be taught programming and would spend most of his time at it. As such he should be reasonably proficient at the task and still have the knowledge of highway engineering

problems which would prevent him from making any serious errors. On specific problems he would work with the individual branch involved and call on their specialized knowledge on technical questions. The Computer Planning Engineer should, therefore, handle the ground work in connection with solving any problem. He would prepare a detailed flow chart to the solution of the problem showing the steps to be followed and the method of handling it in the computer.

b. Programmer Coder

The Programmer Coder would be a Junior Engineer or Junior Mathematician who would be capable of handling some of the routine programming in connection with the revision of existing programs and would be expected to carry out most of the coding of detailed instructions. He should be capable

of taking over the job of Computer Planning Engineer should the need arise. He should also be thoroughly acquainted with the operation of the machine and should be able to handle routine problems in debugging a program and locating errors which fowl up the calculation within the computer.

c. Coder Operator

This individual should probably be at about an Engineering Assistant IV level. He would handle all the routine work in connection with the operation of the computer and the solving of the routine problems. He would be required to edit field books and designs for obvious mistakes. He would edit all output data for correctness and completeness. This man might be used also as a Maintenance Personnel on the computer if it was considered economical, instead of using the services of the manufacturer. He should also be capable of handling the position of the person above or below him.

d. Chief Typist

This person, probably a girl, would be in charge of the key-punching of input data. She should handle all the

secretarial duties as well as the supervising and assisting of the key-punching and varifying. She would be required to learn the operation of the computer sufficiently to take over that field in case of absence of the operator.

e. Typist

The typists would require no particular training other than ability to type. They should be fast and efficient. Production in this line is of prime importance in the efficiency of the operation. This requires a certain type of individual who can get enjoyment out of routine operations carried out over and over again at high speeds.

The computer section must be set up in a very flexible manner so that the loss of one man does not suddenly disrupt the whole operation. There must be an understudy for every position. This is particularly important in the electronic computer field where trained personnel are next to impossible to fine. The need for trained personnel in this field is particularly acute due to the rapid growth

of computer applications and the slowness of educational institutions to realize the need. If the experience in the United States is any guide, then Canadian departments utilizing computer techniques can expect a very rapid turnover of personnel.

H. CHOICE OF COMPUTER

1. Factors to Consider

a. Choice of Basic Unit

The computer which is chosen must be able to handle the majority of the problems given to it quickly and efficiently. Any general purpose computer will handle almost all of the presently available highway programs if they are rewritten for that particular machine. On a long program with a small computer this may entail doing the program in piecemeal by solving one portion at a time and printing out the intermediate results which must later be recombined to arrive at the final answer. This procedure is very seldom an

efficient utilization of computer techniques.

(i) Storage

It is primarily storage capacity which determines whether a certain computer can handle any given problem. True, other items enter into the problem but storage capacity is the greatest single factor. If the problem is too big for the storage provided on the computer, then it is rather difficult to solve the problem. Here again, there are exceptions to the rule. Special magnetic tape units are sometimes provided to give additional storage, or perhaps the program steps are read and executed one step at a time from paper tape or punched cards. These gimicks are the exception rather than the rule and are seldom as efficient as when the complete program, and all intermediate results, can be stored on the main, fast access memory unit. Another way which some units employ to overcome their shortage of memory capacity is to break the particular problem up

into smaller segments. The answers to the first section of the problem are entered as input to the second computation. It can easily be seen that such a process is not a very efficient way of utilizing computer techniques.

The importance of large memory capacity is evident in the newer designs, as larger and larger memories are being provided on even the low priced computers. The I.B.M. 650 which first appeared on the market in December, 1954 had an original memory capacity of 1,000 ten digit words. This has now been increased to 2,000. The Bendix G-15-D which appeared on the market in July, 1955 has a memory capacity of 2,160 eight digit words. The LGP-30 appeared in late 1955 and has a capacity of 4,096 nine digit words. The Stantec Zebra which is not yet commercially available has a memory capaicty of 8,192 nine digit words.

Capacity depends on other factors besides simply the number of storage cells available. For example, some computers have a three address rather than a single address method of instruction. These programs are more efficient in utilization of memory space. To properly assess memory capacity it is necessary to compare the number of memory cells utilized in solving a particular problem on different computers.

(ii) Speed

The speed of a computer will determine how long it will take in a particular computer to perform a given problem. Speeds must be applied to the particular problem under consideration and not to absolute units. For although the addition time on one machine may be twice as fast as that on another, yet it may be no quicker on a particular problem simply because it requires twice as many programs

steps to achieve the same result. The speeds given in the specifications for the particular machines however, must be considered as they are of some significance in the overall speed of the machine.

The following are some of the factors affecting speed:

(1) Input and output

(2) Addition and subtraction time

(3) Access time

(4) Division and multiplication time

(5) Transfer time

(6) Buffering (so as to provide the facility of computation during input)

(7) Program make-up which may make any one instruction capable of performing a larger number of steps on one computer than on another

(8) The internal number system is also important. If the computer works internally in binary

then numbers must be converted from decimal to binary on input and binary to decimal on output.

All of these operations require time. Another method of comparing speed is to look at the time required to do sub-routines.

(iii) Cost

Cost needs no explanation; however, it is a very important consideration in deciding on which computer to purchase. This item will be taken up in comparing the individual makes.

(iv) Accuracy

Accuracy is also a factor which must be analysed on deciding if a particular computer is applicable to your problem. This factor is not even a consideration in our line of work. The computer is so much more accurate than manual methods that to compare the accuracy of two computers would be of no benefit since even the most

inaccurate commercially available computer is entirely satisfactory.

b. Auxiliary Equipment

Punched card computers necessitate a heavy expenditure on auxiliary equipment to handle the cards. This type of installation is a requirement where large quantities of input and output data are being handled as opposed to problems where the input and output is small in comparison to the amount of calculation. Thus it may be seen that the tape input computers can operate with very little auxiliary equipment on typical scientific problems while punch card computers with the auxiliary equipment is a requirement for data processing problems.

c. Personnel to Run a Computer Center

The number of personnel needed to handle the work on a computer depends on several factors.

(i) Type of Computer

Tape input computers usually require less personnel than the punched card computers. As found in

a previous portion of this thesis the average staff of the I.B.M. 650 (which is a punched card computer) in highway work is fifteen, while the average staff for the Bendix G-15-D (a tape input computer) is five. These two computers are not doing exactly the same work.

(ii) The Amount of Input Data Required

Where there are large quantities of input data to prepare key punch operators are required to handle this work. It is generally found that punch cards are faster to prepare than tapes primarily because of the ability to use format control with punched cards thus reducing the total volume of punching.

(iii) The Amount of Programming Which is Required

Programmers are required to prepare the basic method of solution to the computer. The number of programmers required depends on:

(1) The complexity of the programs to be solved

(2) The number of different types of problems to be solved

(3) The number of usable programs which have been previously prepared and are available for the computer.

d. Office Space

(i) Size

The office must be large enough to handle:

(1) Personnel at approximately one hundred square feet per person.

(2) Computer and auxiliary equipment.

(3) Storage and filing area.

(ii) Ventilation and power requirements

All computers give off heat in proportion to their power intake. When the temperatures around the computer become greater than ninety degrees

Fahrenheit the computer may begin to act up but then so will the operators. The larger units such as the I.B.M. 650 require air-conditioning to dissipate the heat produced. The heat produced from the small units may be handled by the use of fans except in the case of a poorly insulated building in the middle of the summer when air-conditioning may be required. With the newer types of computers where tubes are being replaced by transistors the heat given off by the computer may be of a negligable amount. The Recomp II for example draws only o.4 kilowatts which is comparable to an electric toaster. Special wiring of the office may a requirement for some computers such as the I.B.M. 650 which draws 220 volts and 100 amps.

(iii) Weight

The weight varies depending on the type of computer. The I.B.M. 650 weighs around 6,000 lbs.

The Recomp II has a total weight of only 200 lbs. The weight of the computer may be an important consideration where the available office space is not designed to carry this type of load. Bracing of the floor may handle the load in some instances.

e. Programming

(i) Complexity of Machine Language

A machine language program is a program written for the computer in which the instructions may be operated on directly without first going through an assembly interpretive or compiler routine. The difficulty of writing a machine language program for a computer should be given serious consideration when choosing a machine. Every highway department which uses a machine is faced with the problem of writing programs. The simpler it is to write the program, the better. Months and perhaps years may be spent writing a program on a computer with a complicated machine language code while the same

job might be carried out in a matter of weeks in a simpler code.

(ii) Programming Aids

To help overcome the difficulty in programming manufacturers have devised various automatic coding techniques.

(1) Assembly Routine. Assembly routine enables a programmer to write the instructions in an alphabetic notation which is later converted into a machine language program by a program within the computer. The assembly routine may also be set up to optimize the program and thus produce an efficient machine language program. Such a method is employed in the S.O.A.P. programming technique for the I.B.M. 650.

(2) Interpretive Routine. A program written for an interpretive routine is prepared

similar to the assembly routine, the main difference being that in an interpretive routine a machine language program is never prepared but each instruction much be interpreted by the sub-routine within the computer. Such a system may have advantages for short one or two shot problems but is very inefficient for long repetitive calculations. With an interpretive routine the memory space may be reduced by one-half. The time required to carry out each calculation may be ten times as long as for a machine language program. The Bendix G-15-D machine uses an interpretive routine.

(3) Compiler. A compiler is a program within the computer designed to accept statements from a flow chart and produce an optimized

machine language program. This is the ultimate in programming aids for it eliminates the detailed programming almost entirely. The compiler is being developed and improved for almost every make of computer though some are much more advanced than others. One compiler entitled "IT" has been developed to transpose the machine language of one computer to the machine language of another make of computer. "IT" is available on the I.B.M. 650, Datatron, Univac and Bendix G-15-D. As yet the compilers can handle only relatively short problems due to the difficulty in checking it out.

(iii) Programs Available

Some of the programs available in the highway engineering field are listed in the Appendix.

Despite the apparent scope of the programs available on every conceivable field it is found that there are very few "canned" programs available which may be used directly. The original flow charts are certainly an aid in writing a new program but the detailed coding is usually so complicated as to be next to impossible to follow on long programs. Thus new programs are written having very little difference from the older ones, simply because the originals could not be readily understood. No stock of "canned" programs can substitute for a good programmer utilizing a computer which has a simple program code.

f. Maintenance and Service Agreements

Computers have a very high performance record. As the transistors replace tubes this performance record should be even better. Computers do however, break down on occasion.

How serious this breakdown will effect the scheduling of the work will determine what type of service agreement is required. The most desirable set up is to have a service man with the machine at all times. This is very seldom economically feasible except on large installations. A service man that can be reached within a radius of ten miles is usually considered quite satisfactory. If a service man has to be flown in from another city costly delays may result. This type of an arrangement should be agreed to only after the computer has proven itself to be trouble free for long periods of time at the particular installation.

g. Training of Personnel

Most manufacturers provide training for programmers free of charge in conjunction with the installation of a computer. These courses usually range in length from two weeks to one month. A one to two week course is usually given to the computer operator. It is not expected that these personnel will become very proficient at their task for at least a year. Thus, the first year's operation on a computer cannot be considered as a

very good guide for establishing comparisons with other methods.

2. Computer Investigation

a. Computers Available

There are literally hundreds of different makes of computers which are available. The following makes were investigated as possible choices for use by the Saskatchewan Department of Highways:

(i) I.B.M.

  (1) 650
  (2) 610
  (3) 704
  (4) 705
  (5) Ramac
  (6) 602-A
  (7) 604
  (8) 607

(ii) Remington-Rand

    (1) Univac 120

    (2) Univac file computer

    (3) Univac I and II

(iii) Bendix

    (1) G-15-D

(iv) Royal McBee

    (1) LGP-30

(v) Burroughs

    (1) E-101

    (2) Datatron - 205

    (3) Datatron - 220

(vi) Autonetics

    (1) Recomp II

(vii) Standard Electric

    (1) Stantec Zebra

(viii) Alwac III

(ix) National Cash Registers

    (1) 304

b. Eliminated Due to Cost

The following makes of computers were immediately eliminated due to the high cost:

(i) I.B.M. 704

(ii) Univac I and II

(iii) Univac file computer

(iv) Datatron 220

c. Primarily Business Machines

The following machines were eliminated since they are primarily business machines as opposed to scientific machines:

(i) National Cash Register 304

(ii) I.B.M. Ramac

d. Too Slow or Too Small

Some computers were found to be too slow or had too small a memory capacity to efficiently handle the work which was anticipated for them. The following computers were

eliminated primarily for this reason:

(i) I.B.M. 602-A

(ii) I.B.M. 604

(iii) I.B.M. 607

e. Other factors Used in Making the Choice

The above mentioned elimination process was used to reduce the list of possible computers to those shown on Fig. 3. Anyone of these computers might be practical to handle certain phases of the problems which the Saskatchewan Highway Department have to solve. Memory requirements make the I.B.M. 610, Univac 120 and E 101 rather inefficient for the main problems. These computers would be practical only if they operated at a faster speed than other makes with larger memories sold at comparable prices. The E 101 and Univac 120 both use plub-boards to control the operation of the program. This system of control is found primarily in the older makes of computers and is very inflexible in program manipulation. The I.B.M. 610 is a new machine which has just been brought out.

It is very limited in application due to its small memory and slow speed. Its main selling point is its ease in programming and application. This criterion is of some importance but not worth the sacrifice in speed.

The Autonetics Recomp II and Standard's Stantec Zebra are both very powerful machines in the low priced field. They do have definite potential but are new on the commercial market. They perhaps should be given further consideration in a few years time when they have been proven in the field. At the present time the Saskatchewan Highway Department does not have the work which would require it to take a chance on a non-proven make.

Insufficient material was obtained on the Standard E.R. 56 but it is higher priced than the Stantec Zebra and therefore is not warranted at this time.

The Datatron 205 and the Alwac III both have potential for highway engineering purposes. They are, however, more expensive than other makes which have adequate capacity.

This very sketchy analysis has disposed of all but three of the computers leaving for detailed consideration the I.B.M. 650, the Bendix G-15-D and the LGP-30. Each of these machines is being used by at least one highway department and many highway consultants. There are twenty highway departments in the United States and Canada who have the I.B.M. 650, three with the Bendix G-15-D and one with the LGP-30.

f. Why I.B.M.?

Why have so many departments decided on using the I.B.M. 650? The reasons behind this choice are many and varied. I will touch on a few. Univac was the first computer on the market. For a short while they held the market. They made a few mistakes, however, which cost them their reputation. They produced a fine machine but they did not prepare and teach the customer sufficiently in the details of handling it. General Electric had one of the first large Univacs but it was a white elephant as there was not sufficient knowledge of the computer by those who were supposed to use it. On the other

hand, when I.B.M. got into the field they made few mistakes. The computer itself was thoroughly tested. The problem for which the computer was to be used was thoroughly analysed to decide on the best method of approach and the best equipment to go with the installation. I.B.M. made sure that its customers received an accurate schooling in the operation of their computer to get the most out of it. They believe in the principle that the computer unit itself was only half of the problem in applying electronic computer techniques; the rest depended on the men working with the machine. The strategy paid off and soon I.B.M. became the foremost seller of computers. Now they are so well known and so much respected that when the average man thinks of a computer, the first name they think of is I.B.M.

California was one of the first highway departments to use an electronic computer for highway engineering work. That department had previously used I.B.M. punch card equipment and a 604 electronic calculator. It was, therefore, a logical step for them to obtain an I.B.M. 650

As the number of 650's in the field increased, it became harder and harder for the newer makes of computers to get a foothold. Even though they could show a comparable machine for less cost, still they had to fight against the universally accepted name of I.B.M. Univac, of course, was in the field with their U-120 but it was limited in application. During this head start I.B.M. collected and developed programs, in the highway field, which gave another competitive edge.

Since this initial period, Bendix has broken into the field and now has a computer at Wyoming, Michigan and Illinois Highway Departments, as well as at several consultant firms in the highway engineering field. In the last two years through an active users organization they have developed programs so that they can now meet I.B.M. in this respect.

g. Final Choice of Computer

On Fig. 3 is an economic analysis of the factors affecting the choice of a computer for the Saskatchewan Highway Department. This particular analysis gives a slight advantage

to the use of the LGP-30. Let it be stated at this point that slightly different conditions within the department could easily have resulted in one of the other makes having the advantage. The analysis given on Fig. 3 is self explanatory.

3. Purchase or Lease

In considering whether to purchase or lease a computer it is necessary first of all to consider the evolution in the field. Electronic computers and electronic computer techniques are changing very rapidly. Faster and more powerful units are constantly being provided at lower costs. These newer techniques are out-dating the older models and methods. To purchase a computer in a field which is changing so fast would be a mistake at least until such time as a particular machine has proven itself in the department. Nearly all companies provide an option-to-buy agreement, under which approximately fifty percent of the rental paid on the computer will be reduced from the purchase price within the period of the first year. It is interesting to note that all of the

State Highway Department in the United States are leasing their computer, with the exception of one 604, which is perhaps more correctly called an electronic calculator.

ELECTRONIC COMPUTERS IN HIGHWAY ENGINEERING.

	A. Using Computer 1. (1) Lease % of Computer Time	(2) Use Consultants % of Computer Time	(3) Own Computer	2. Make of Computer Used	3. Length of Time These Techniques Used — Months	4. a Design Earthwork (1)	Miles / Month (2)	% by Computer (3)	Cost / Mile (4)	Sections / Mile (5)	Points / Section (6)	b Final Pay Quantities (1)	Miles / Month (2)	% by Computer (3)	Cost / Mile (4)	c Structural (1)	% by Computer (2)	d Traffic and Planning (1)	% by Computer (2)	e Hydrology and Hydraulics (1)	% by Computer (2)	f Photogrammetry	g Traverse Problems (1)	Land Areas (2)	Geometric Alignment Problems (3)
CANADA																									
Alta.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B.C.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Man.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N.B.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nfld.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N.S.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ont.	[illegible]	100%	—	IBM 650	24	Yes	45	100%	Consult. $100 Own $30	100	12	Yes	By Aug./58 22	50	Consult. $100 Own [illegible]	Yes	5% (More Soon)	Yes	10% A.A.R.T.	No	(Some Soon)	Considering	Yes	Yes	No
P.E.I.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Que.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sask.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fed.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
U. S. A.																									
Ala.	100%	No	No	IBM 650	14	Yes	50	95%	$75①	150	15	Yes②	60	10%	$75①	Yes	5%	Yes②	1%	Yes②	1%	No	No	No	No
Ariz.	100%	—	—	U 120	28	Yes	12	50%	$45	104-160	7-12	Yes	14	70%	$16	Yes	Just Started	No	—	No	—	Yes	Yes	No	Yes
Ark.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Calif.	100%	No	No	IBM 650 + 604	36	Yes	291①	?	$50②	63	18	Yes	No Breakdown — Design and Final Pay Quantities			Yes	?	Yes	?	No	—	Yes	Yes	Yes	Yes
Colo.				IBM 650																					
Conn.	100%	No	No	U 120	Start	Yes	Not Complete		7:1①	120	20	No	(Coming)			No	—	Yes	20%	No	—	No	Yes	No	No
Dela.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fla.	100%	No	No	IBM 650	8	Yes	?	?	?	?	53	No	—	—	—	No	—	Yes	15%	No	—	No	Yes	Yes	Yes
Ga.	100%	—	—	IBM 650	18	Yes	125	75%	$16.36	52	8	Yes	40	40%	$18.74	Yes	100%	No	—	No	—	Yes	Yes	Yes	—
Idaho				U 120																					
Ill.	Yes	No	No	G-15-D	—	Yes	17	20%	$50	70	15	No	—	—	—	Yes	5%	No	—	No	—	No	Yes	No	No
Ind.	100%	0%	No	IBM 650	10	Yes	(Just Starting)			80	18	(Considering)				Yes	10%	No	—	No	—	No	Yes	No	No①
Iowa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Kan.	Yes	—	—	IBM 650	6	Yes	(Just Starting)			80-100	20-30	Yes	40	70%	$50	Yes	Just Start.	Yes	10%	No	—	No	No	No	Yes
Ky.	100%	—	—	IBM 650	9①	Yes	Just Trial	Compl. Run	$12	110	12	Coming	No	No	$10	Yes	5%	No	—	No	—	No	Yes	Yes	Yes
La.	Yes	—	—	U 120	14	Yes	50	50%	$55	100	12	Yes	50	75%	$70	No	—	No	—	No	—	No	Yes	Yes	No
Maine	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Md.	100%	—	—	U 120	10	Yes	25	60%	$250①	112	30	No	—	—	—	Yes	5%	Yes	75%	No	—	No	Yes	No	Yes
Mass.	100%	—	—	IBM 650	12	Yes	Testing Only		$100	110	16	No	—	—	—	No	—	No	—	No	—	Yes	Yes	Yes	Yes
Mich.	100%	No	No	G-15-D	22	Yes	9	30%	$43.48	53-60	12-15	No	—	—	—	Yes	35%	No	—	No	—	No	Yes	No	Yes
Minn.	100%	No	No	U 120	18	Yes	78	50%	$33	200	10	No	—	—	—	No	—	Yes	5%	Yes	?	No	Yes	No	Yes
Miss.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mo.	Yes	No	—	IBM 650	9	Yes	20	50%	$50	60	12	No	—	—	—	Yes	20%	Yes	30%	Yes	10%	No	—	—	Yes
Mont.	100%	No	No	IBM 602A	38	No	—	—	—	211	12	Yes	53	85%	$26	No	—	No	—	No	—	No	No	No	No
Neb.	Yes	No	No	IBM 650	16	Yes	50-100	80-85	$35-$50	80	15-20	Yes	25	95%	$25-$30	Yes	5-10%	Very	Minor	No	—	Yes	Yes	Yes	Yes
Nev.																									
N. Hamp.	Service Bureau Yes	Yes	No	IBM 650	18	No	—	—	—	115	18	Yes①	6-8①	—	?	No	—	No	—	No	—	No	No	No	No
N.J.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N. Mex.	No	Yes	Yes	IBM 604	?	Yes	Selected Projects		$400	75-100	8-16	No	—	—	—	No	—	—	—	No	—	No	No	No	No
N.Y.	Yes 12%	No	No	IBM 650	13	Yes	5	5%	?	100	20	Yes	5	5-10%	?	Yes	?	Yes	50-100	No	—	No	No	No	No
N.C.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N. Dak.	100%	No	No	LGP 30	1	Yes	Starting		Now	60	14	No	—	—	—	Starting		No	—	No	—	No	No	No	No
Ohio	Yes	—	—	IBM 650	16	Yes	30	20%	$50	100	40	No	—	—	—	Yes	10%	No	—	No	—	Yes	Yes	Yes	Yes
Okla.	Yes	—	—	U 120	18	Yes	40	30%	$30	125	18	No	—	—	—	No	—	No	—	No	—	No	Yes①	Yes②	No
Ore.	100%	—	—	IBM 650	13	Yes	75①	50%	$25②-$60③	50-100	20	Yes	25	100%	$10	Yes	60%	Yes	?	No	—	Limited Yes	Yes	Yes	Yes
Pa.	Yes	—	—	IBM 650	1	Yes	Just		Beginning		?	Yes	?	?	?	Yes	?	Yes	?	?	?	Considering	?	?	?
R.I.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S.C.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S. Dak.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tenn.	[illegible]	Yes	No	IBM ?	4	Yes	Small		?	10	?	No	—	—	—	No	—	Yes	8%	No	—	No	No	No	No
Texas	100%	No	No	IBM 650	18	Yes	100	<5%	$13-$100	83-100	16	Yes	Small		$5-$10	Yes	80%	No	—	Yes	10%	No	Yes	Yes	No
Utah	Service Bureau Yes	—	—	IBM 650	4	Yes	20	40%	$80	104	4-30	Yes	10	30%	$80	No	—	Yes	10%	No	—	Yes	Yes	Yes	No
Va.	100%	No	No	IBM 650 IBM 604	6	Yes	(Just Beginning)			130	15	No	—	—	—	No	—	Yes	Small	No	—	Limited Yes	Yes	No	No
Ver.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Wash.	100%	No	No	IBM 650	21	Yes	150	80%	$25	120	6	Yes	30	50-60%	$25	Yes	5-10	Yes	5-10	No	—	Yes	Yes	No	Yes
W. Va.	Yes	—	—	U 120	2	Yes	?	73%	?	120	40	No	—①	—	—	Yes	—①	Yes	35	No	—	No	Yes	Yes	Yes
Wisc.	100%	No	No	IBM 650	17	Yes	50	75%	$65	65-75	15-20	Yes	75	100%①	$60	Yes	5-10	Yes	5	No	—	Yes②	No	No	No
Wyo.	100%	No	No	IBM 604	10	Yes	15	25%	$150	60-75	10-15	No	—	—	—	No	—	Yes	20%	No	—	Yes	No	No	No
D.C.	Yes	Yes	No	IBM 705 Univac I	12	No	—	—	—	—	—	No	—	—	—	No	—	Yes	?①	No	—	No	No	No	No

	Some of the Other Problems in Highway Engineering Being Solved on the Electronic Computer	5. a Staff Director	b Programmers	c Coders	d Machine Operators	e Key Punch Operators on Flexowriter	f Others	Total Staff	B. Not Using Computer 1. Considering	2. Undertaken Study	3. Computer on Order	Date of Correspondence From	Notes	Total State or Provincial Highways 1956 — Miles	State or Provincial Expenditure on Highway Construction 1956 — Millions of Dollars
CANADA															
Alta.	—	—	—	—	—	—	—	—	No	No	No	4/7/58		5,600	38
B.C.	—	—	—	—	—	—	—	—	Yes	Yes	No①	7/7/58	① Is About To Order A Computer.	?	62
Man.	—	—	—	—	—	—	—	—	Yes	No	No	15/7/58		3,800	13
N.B.	—	—	—	—	—	—	—	—	Yes	Yes①	No	4/7/58	① Partial Study	2,500	14
Nfld.	—	—	—	—	—	—	—	—	No	No	No	7/7/58		2,800	7
N.S.	—	—	—	—	—	—	—	—	No	No	No	30/6/58		1,700	12
Ont.	Location Surveys, Basic Volume Reference Table, Standard Numerical Methods such as Matrix Inversion, Matrix Multi and Variance Determination, Significance Analysis.	1	3	—	2	2	8	16①	—	—	—	27/6/58	① Includes Some Engineering Aids and Typists	8,700	88
P.E.I.	—	—	—	—	—	—	—	—	No	No	No	25/6/58		?	3
Que.	—	—	—	—	—	—	—	—	No	No	No	2/7/58		6,800	83
Sask.	—	—	—	—	—	—	—	—	Yes	Yes	No	—		8,200	17
Fed.	—	—	—	—	—	—	—	—	Yes	Yes	No	4/7/58		3,600	
U. S. A.															
Ala.	Bid Tabulations	½	1	1	1	3	—	6½③	—	—	—	25/7/58	① Expected to Improve Soon. ② Just Beginning. ③ Are Planning to Add an Engineer and More Programmers.	7,300	34
Ariz.	Seeding Area, Tons Material, Simultaneous Linear Equations, Symmetrical and Asymmetrical Matrices.	1	2	2①	—	4	—	9	—	—	—	1/7/58	① Part Time.	4,200	11
Ark.	—	—	—	—	—	—	—	—	Yes	Yes	IBM 610 Sept./58	26/6/58		10,000	13
Calif.	Vertical Alignment, 3 Centre Curve.	1	6	—	3 + 8	14	—	32	—	—	—	17/7/58	① Includes Design and Pay Quantity Computations. ② Overall Cost — All Types of Highways.	13,800	129
Colo.														8,000	15
Conn.	—	1	3	10②	5③	11③	5③	21③	—	—	—	2/7/58	① Estimated Ratio of Cost Over Manual Methods. ② Part Time in Field. ③ Combined with Accounting.	3,000	188 (158 on Toll Road)
Dela.	—	—	—	—	—	—	—	—	Yes	Yes	—	30/6/58		500	7
Fla.	Bid Tabulations, Solution of Simultaneous Linear Equations, Payroll, Time Distribution.	1	2①	—	2②	5③	5③	10	—	—	—	2/7/58	① Full Time. ② One of These is a Part Time Operator and Programmer. ③ Share with Data Processing Division	10,200	66
Ga.	Payrolls, Social Security, Appropriation Accounting.	1	2	—	1	6	—	10①	—	—	—	30/6/58	① Full Time — Also Several Programmers in Bridge Department.	15,100	23
Idaho														4,700	15
Ill.	Azimuth Determination, Embankment Stability Design, Letting Cost Distribution.	—	1	1	1	1	—	4	—	—	—	30/6/58		12,500	46
Ind.	—	—	4	—	—	1	—	3	—	—	—	21/7/58	① Being Programmed.	10,700	18
Iowa	—	1	2	—	2	3	—	18	Yes	Yes	IBM 650 Sept./58	30/6/58		9,700	48
Kan.	—	1	7	—	2	3	2	17	—	—	—	27/6/58		10,100	25
Ky.	Used by Accounting Department, Bid Tabulations.	1②	4	3③	1	2	1	12	—	—	—	30/6/58	① Since Installation. ② Engineering Special Assignment. ③ Summer Students	13,000	13
La.	Maintenance Cost Estimates.	—	2	—	3	7	4	16	—	—	—	30/6/58		4,200	48
Maine	—	—	—	—	—	—	—	—	No	Yes	No	30/6/58		3,300	10
Md.	Transitions (Horizontal and Vertical), Soil Problems (Proctor — Physical)	1	2	—	2	1	—	6	—	—	—	3/7/58	① This Price Includes Used Machine Time.	4,700	34
Mass.	Reduction of Geodetic Taping.	1	4	—	1	1	1	8	—	—	—	7/7/58		2,200	62
Mich.	—	1	2	—	1	2	—	2	—	Yes	—	30/6/58		8,400	78
Minn.	Distance and Bearing Between 2 Points, Balancing and Haul, Clearing and Grubbing, Grades, 3 Centre Curve for Interchange.	1	3	—	1	2	—	?	—	—	—	2/7/58		12,000	38
Miss.	—	—	—	—	—	—	—	—	Yes	Yes	IBM 650 Jan./59	30/6/58		10,300	11
Mo.	—	1	3	—	2	2	—	14	—	—	—	30/6/58		8,900	27
Mont.	—	—	—	—	4	6	—	10	Yes	Yes	—	1/7/58		5,900	9
Neb.	—	1	2① 3②	—	4	4	1	13②	—	—	—	2/7/58	① Part Time. ② Full Time	9,300	11
Nev.														2,200	2
N. Hamp.	—	None							Yes①	Yes	No	3/7/58	① Borrow Pits Only.	1,600	13
N.J.	—	—	—	—	—	—	—	—	Yes①	Yes①	No	3/7/58	① For Bridge Use Only — Probably Use Outside Firm.	1,800	21
N. Mex.	Cost Accounting, Fiscal Controls, General Statistics.	—	1①	—	3	8	—	12	Considering Expanding to IBM 650			1/7/58	① Tabulating Equipment Supervisor Who Programs and Codes Work Now Being Done.	11,500	8
N.Y.	Weighted Bid Prices.	1	1① 4② 5③	—	3	6	5	22	—	—	—	8/7/58	① Full Time. ② Part Time. ③ Inactive.	13,100	134
N.C.	—	—	—	—	—	—	—	—	Yes	Yes	IBM 650 Dec./58	30/6/58		12,300	25
N. Dak.	—	—	2	—	—	1	—	3	—	Yes	—	16/6/58		6,500	11
Ohio	Analogue — Digital Converter on Kelsh Plotter, Formulae Reduction, Progress Reports.	1	5	—	3	4	1	16	—	—	—	2/7/58		18,300	31
Okla.	Bid Tabulations, Cost Accounting, Curved Bridge Geometry, Computing Accounting.	1 1	1 —	— —	2 1	3 3	— 1	7 6	—	—	—	26/6/58	① Starting. ② In Right-of-Way Only.	10,900	30
Ore.	—	1	1④ 7⑤	—	2	13	5	23④ 7⑤	—	—	—	2/7/58	① Single Trials. ② Cost of First Trial. ③ Cost of Next Trial Grades. ④ Full Time. ⑤ Part Time.	5,800	9
Pa.	—	Not		Organized			Yet		—	—	—	14/7/58		14,700	95
R.I.	—	—	—	—	—	—	—	—	No	No	No	11/7/58		900	5
S.C.	—	—	—	—	—	—	—	—	Yes	Yes	No	27/6/58		9,000	15
S. Dak.	—	—	—	—	—	—	—	—	No	Yes	No	28/6/58		6,700	15
Tenn.	—	1	2	2	—	2	—	7	Yes	—	—	30/6/58		8,400	36
Texas	—	—	6	—	2	4	1	13	—	—	—	30/6/58		51,700	124
Utah	—	1	—	—	1	3	—	5	—	Yes	IBM 650 Jan./59	20/6/58	① Experimenting Using Dictaphone to Read From Contours.	5,500	3
Va.	Vertical Curve Sight Distance Table, Tabulation of Construction Bids.	1	3	—	①	①	①	①	[illegible]	[illegible]	[illegible]	3/7/58	① Large Accounting Station [illegible]	[illegible]	[illegible]
Ver.	—	—	—	—	—	—	—	—	Yes	No	No	15/7/58		8,500	51
Wash.	Maximum Density of Granular Materials, Slope Stability Analysis, Unit Bid Price Analysis.	4 + 1	2½	—	2	6	2	17½	—	—	—	30/6/58	① Includes Reruns.	4,100	23
W. Va.	—	—	5	—	4	6	—	15	—	—	—	26/6/58	① Under Development.	5,000	3
Wisc.	Centre Line Grade, Roadside Template Design and Others.	—	1	—	1	2	—	4	—	—	—	2/6/58	① All Grading Projects. ② Original Cross-Sections Taken From Aerial Contour Maps.	11,500	3
Wyo.	Entire Process of Bid Tabulations.	—	1	—	—	2	—	3	—	Yes	IBM 650 ①		① May Obtain Datatron 205 or G-15-D	5,000	8
D.C.	None.	None							—	Yes	No	27/6/58	① Uses on O. and D. Studies.		4

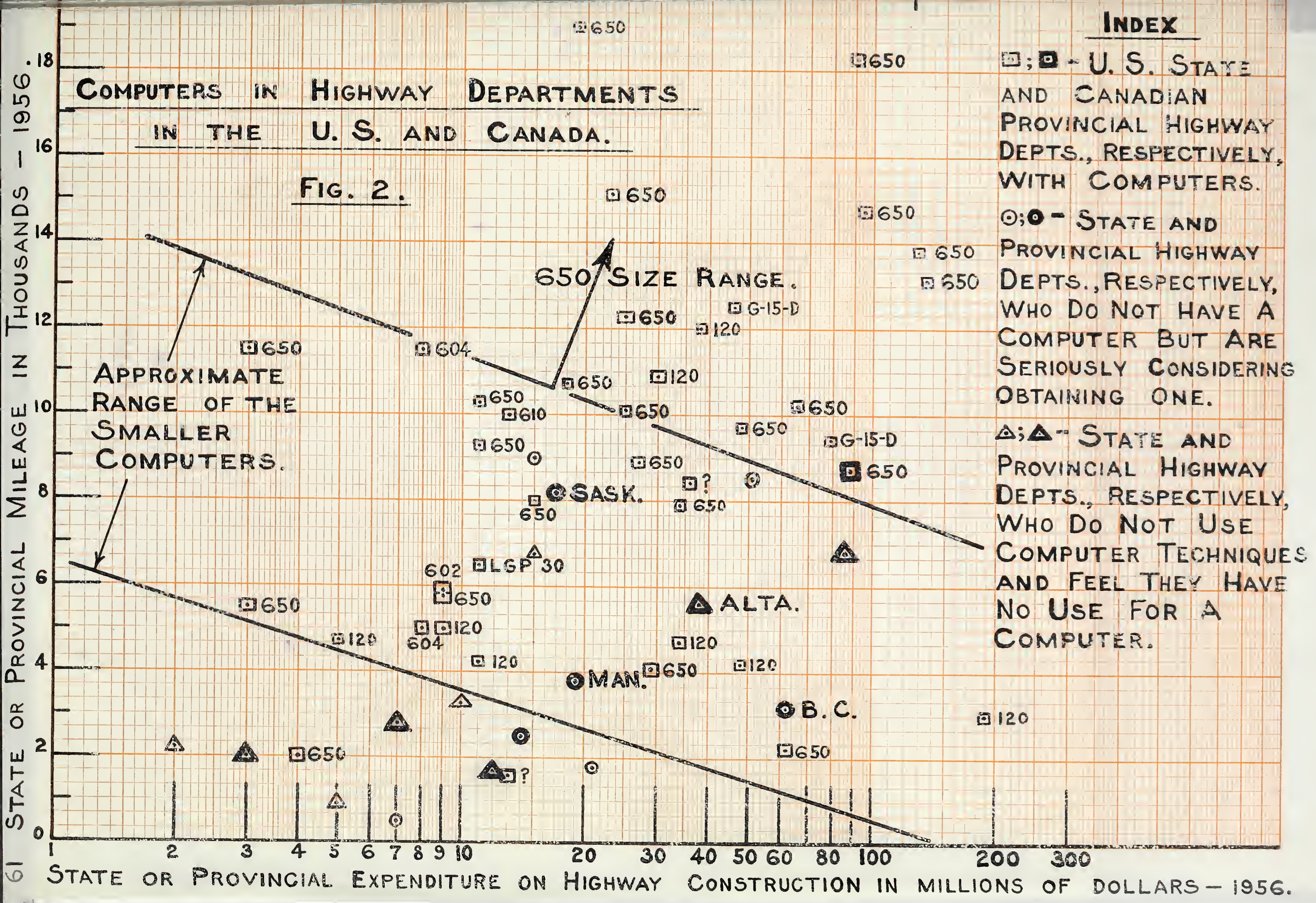
FIG. I.

SUMMARY

	Number in U.S.	Number in Canada
Number of Highway Departments.	49	11
Number Using Electronic Computers for Highway Engineering Calculations.	37	1
Number Who Do Not Use Computers But Who Have One On Order.	4	0
Those Who Do Not Use A Computer But Who Are Seriously Considering Doing So.	4	5
Those Who Do Not Feel They Have A Need For a Computer.	3	5
Number on Which We Have No Information.	1	0
MAKE using or on order		
IBM 650	25	1
IBM 604	2	—
IBM 610	1	—
IBM 602A	1	—
IBM 705	½	—
UNIVAC I	½	—
UNIVAC 120	8	—
G-15-D	2	—
LGP 30	1	—
TOTAL	41	1

COMPUTERS IN HIGHWAY DEPARTMENTS IN THE U. S. AND CANADA.

FIG. 2.



COMPARISON OF COMPUTERS

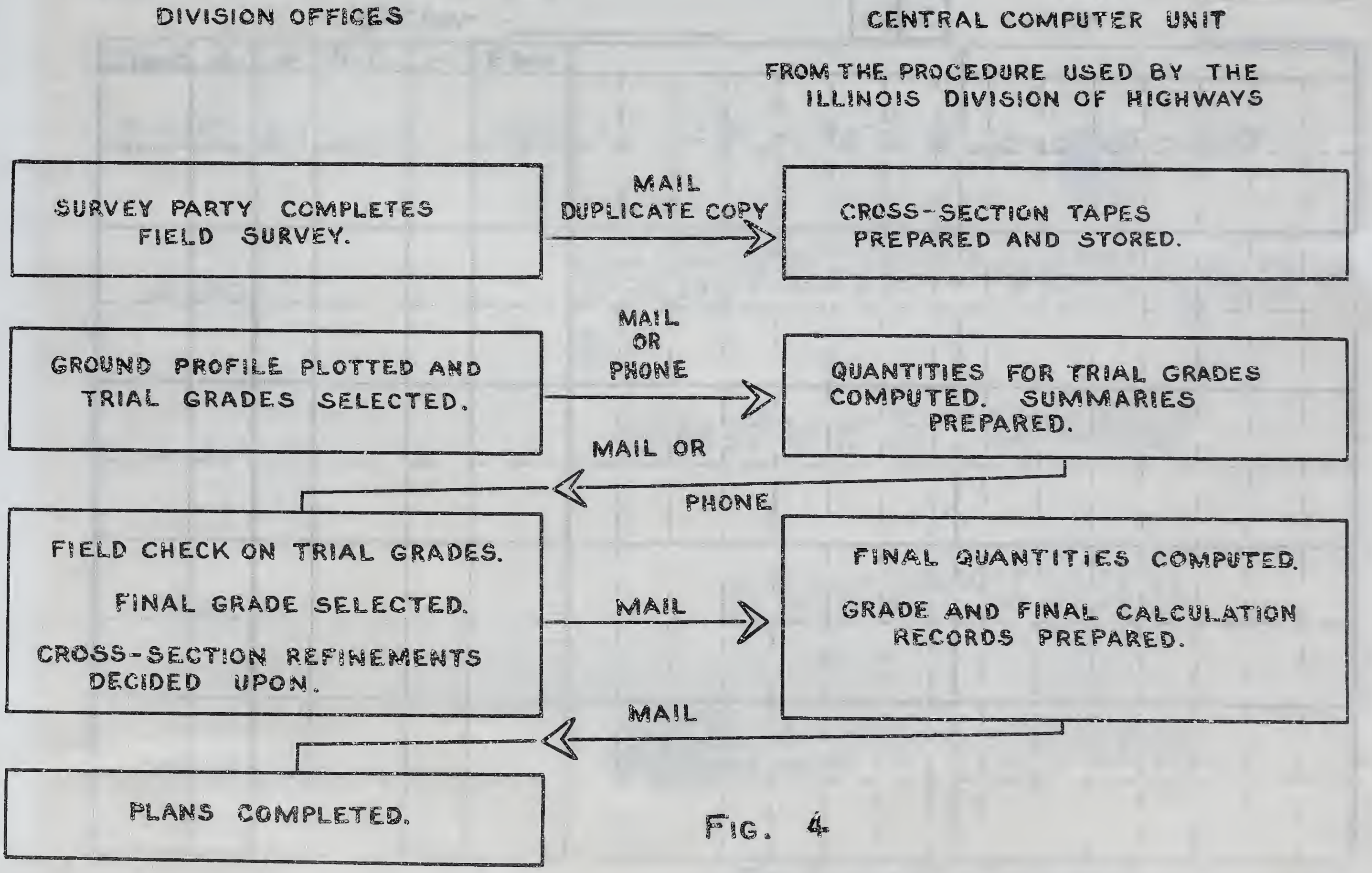
	Item	IBM 650	IBM 610	U 120	G-15-D	LGP-30	E-101	RECOMP II	STANTEC ZEBRA	DATATRON 205	ALWAC III E
COST/MONTH	BASIC UNITS	Consul, Power Unit, 533 In-Out Device. } $4200/Mo.	Computer, Input and Output Device. } $1200 ①	(Arizona) $1350 ①	G-15-D, Typewriter, Tape Punch, Photoelectric Reader. } $1895	L.G.P.-30, Flexowriter } $1250	E-101 $1,110 ①	Computer, Photoelectric Reader, High Speed Tape Punch. } $2100	Computer, Power Unit Control, High Speed Reader, High Speed Punch, Page Teleprinter } $2100 ②		Computer with Index, Typewriter, Paper Tape In and Out. } $2750 ①
	ADDITIONAL UNITS	Alpha Device – $500 3-Key Punch – $123 Sorting Mach. – $65 Verifier #56 $52 Tabulator – $490	2½ Typewriters 2½ @ $175 } $425 Approx.	3 Key Punchs Sorting Machine Verifier Translator Interpreter Reproducer } ?	2½ Flexowriters @ $175 } $425 Approx.	2½ Flexowriters @ $175 } $425 Approx. 1 Photoelectric Reader Model 200 } $225	Tape Input 220 Word Memory Typewriters	3 Punches $300	3 Punches $300 1 Set Tape Editing Equipment $110		
	Sub Total	$1230	$425	$730	$425	$650		$300	$410		
	INCIDENTALS										
	Mail	$40	$40	$40	$40	$40	$40	$40	$40	$40	$40
	Supplies	$200	$200	$200	$200	$200	$200	$200	$200	$200	$200
	Sub Total	$240	$240	$240	$240	$240	$240	$240	$240	$240	$240
	PERSONNEL										
	Key Punch Operator	3 @ $220 $660	4 @ $220 $880	4 @ $220 $880	4 @ $220 $880	4 @ $220 $880		4 @ $220 $880	4 @ $220 $880		
	Chief EPO	$300	$300	$300	$300	$300		$300	$300		
	Mach. Oper.	$320	NIL	NIL	NIL	NIL		NIL	NIL		
	Prog. & Coder	$400	400	$400	$400	$400		$400	$400		
	C.P.E.	$600	600	$600	$600	$600		$600	$600		
	Sub Total	$2280	$2180	$2180	$2180	$2180		$2180	$2180		
	OFFICE										
	Min. Space	@ $0.20 600 sq. ft. $120	100 ft.² @ $0.20 $20	$30	100 ft.² @ $0.20 $20	100 ft.² @ $0.20 $20	$20	100 ft.² $20	500 ft.² $.100	400 ft.² $80	
	Weight	6000 lbs. $20	750 lbs. Nil	Nil	965 lbs. Nil	800 lbs. Nil		400 lbs. Nil	3400 lbs. $10	3200 lbs. $10	
	Power	18 KW × 72 × $0.03 $40	2.2 KW × 154 × .03 $10	$10	3.8 KW × 154 × .03 $18	1.5 KW × 154 × .03 $7	$7	.4 KW × 154 × .04 $3	5KVA × 154 × 0.03 $23		
	Ventilation and Humidity	60,000 B.T.U./Hr. $ Vent. Unit Req'd, 20 95% Max.	Fan Req'd. $3	$3	Internal Forced Air Provided, Fans Req'd. $5	Internal Forced Air Provided, Fans Req'd. $3	$3	No Fans Req'd. 0	10,000 B.T.U., Fan $5	Vent. Req'd. $20	11,000 B.T.U. Fan. $10
	Sub Total	$200	$33	$43	$43	$30		$23	$138	$110	
	ADDITIONAL PROGRAM	$\frac{1500}{48}$ \$30	NIL	$\frac{1500}{48}$ \$30	$\frac{1500}{48}$ \$30	$\frac{1500}{48}$ \$30		$\frac{8000}{48}$ \$166	$\frac{16{,}000}{48}$ \$332		
	TOTAL	$8180	$4078	$4573	$4813	$4380		$5009	$5400		
COMPUTER COST/MI.	TIME FOR COMPLETE SECTION: 1st Run Design	3 Sec.	Insufficient Memory Storage Available For Design Earthwork Program	30 Sec.	10 Sec.	12 Sec.	Insufficient Memory Storage Available For Design Earthwork Program				
	2nd & 3rd Run	(Calif.) 12 Sec. × 2 24 Sec.		(Minnesota) 96 × 2 192 Sec.	(Ill & Mich.) 50 × 2 100 Sec.	(N. Dak.) 60 × 2 120 Sec.					
	Finals	(B.P.R. Div. 8) 3 Sec.		30 Sec.	10 Sec.	12 Sec.					
	Sub. Total	30 Sec.		252 Sec.	120 Sec.	144 Sec.					
	+10%	3 Sec.		25 Sec.	12 Sec.	14 Sec.					
	Total	33 Sec. or 0.55 Min.		302 Sec. or 5.03 Min.	132 Sec. or 2.2 Min.	158 Sec. or 2.63 Min.					
	Sections per Year	(500 × 65 × 0.9) = 29,200 Sections/Yr.		29,200 Sections/Yr.	29,200 Sections/Yr.	29,200 Sections/Yr.					
	Computer Time/Mo. in Min.	(200 × 60) = 12,000 Min./Mo.		12,000 Min./Mo.	12,000 Min./Mo.	12,000 Min./Mo.					
	TIME REQ'D Earthwork	29,200 × 0.55 = 16,100 Min./Yr. = 16,100/12,000 = 1.35 Mo.		29,200 × 5.03 = 147,000 = 147,000/12,000 = 12.3 Mo.	29,200 × 2.2 = 64,200 = 64,200/12,000 = 5.34 Mo.	29,200 × 2.63 = 76,800 = 76,800/12,000 = 6.40 Mo.					
	Accounting	0.50 Mo.		1.0 Mo.	Nil	Nil					
	Materials	0.10 Mo.		0.1 Mo.	0.10 Mo.	0.10 Mo.					
	Planning	0.50 Mo.		1.0 Mo.	1.00 Mo.	1.00 Mo.					
	Bridge	0.20 Mo.		0.4 Mo.	0.40 Mo.	0.40 Mo.					
	Survey	0.05 Mo.		0.1 Mo.	0.10 Mo.	0.10 Mo.					
	Incidental Design	0.10 Mo.		0.2 Mo.	0.20 Mo.	0.20 Mo.					
	Program Checking	0.50 Mo.		1.5 Mo.	1.50 Mo.	1.70 Mo.					
	Repair	0.30 Mo.		0.5 Mo.	0.50 Mo.	0.80 Mo.					
	TOTAL	3.60 Mo.		17.1 Mo.	3.14 Mo.	10.70 Mo.					
	Time Wasted	8.40 Mo.		—	2.85 Mo.	1.30 Mo.					
	Overtime Req'd	—		5.1 Mo.	—	—					
	% of Used Time for Earthwork and Repair	$\frac{1.65}{3.60} \times 100 = 46\%$		$\frac{12.8}{17.1} \times 100 = 75\%$	$\frac{5.85}{9.15} \times 100 = 64\%$	$\frac{7.2}{10.7} = 67\%$					
	Cost of Overtime per Month	Nil		$\frac{4573 \times 5.1}{12 \times 1.5} = \$1300$	Nil	Nil					
	TOTAL COST OF COMPUTER TECHNIQUES	$8180/Mo.		$5873/Mo.	$4813/Mo.	$4380/Mo.					
	COST/MI. Charged to Earth Calc.	$\frac{0.46 \times 8180 \times 12}{500 \times 0.30} = \$100/\text{Mi.}$		$\frac{0.75 \times 5873 \times 12}{500 \times 0.30} = \$117/\text{Mi.}$	$\frac{0.64 \times 4813 \times 12}{500 \times 0.3} = \$83/\text{Mi.}$	$\frac{0.67 \times 4380 \times 12}{500 \times 0.3} = \$78/\text{Mi.}$					
SPECIFICATIONS	SPEED Access Time	24 MS.	56 MS.		Gen 14.5 MS Fast Acc 0.54 MS	9 MS		Gen. 8.7 MS. Fast Acc. 0.3 MS.	5 MS.	6 MS.	
	Add or Subt. + Access	0.77 – 10.18 MS.	280 MS	100 MS.	15 – 0.8 MS.	3.86 MS	50 MS.	3.2 MS.	5.3 MS.		1.0 MS.
	Mult. or Div. + Access	13.5 – 17 MS.	1160 MS.	50 MS.	31 – 17 MS.	26 MS.	250 MS	21.1 MS.	16 – 40 MS.		18 MS.
	Block Commands	Good	Good		Good	Poor	Poor	?	Good		
	Min. Access Programming	Easy	No	No	Easy	Difficult	None	?	Easy		
	INPUT Card	80 Column Card 200 Cards/Min. = 260 Char./Sec.		90 Column Card	80 Column Card 17 Char./Sec.				600 Cards/Min.	240 Cards/Min.	100 – 200 Char./Sec.
	Punched Tape					10 Char./Sec.	20 Char./Sec.				10 Char./Sec.
	Magnetic Tape	15,000 Char./Sec.			430 Char./Sec.				25,000 Char./Sec.	6,000 Char./Sec.	
	Photo-Electric Reader				200 Char./Sec.	120 Char./Sec.		400 Char./Sec.	200 Char./Sec.	450 Char./Sec.	200 Char./Sec.
	High Speed Punched Tape				60 Char./Sec.						60 Char./Sec.
	OUTPUT Card	130 Char./Sec.			11 Char./Sec.						100 – 200 Char./Sec.
	Punched Tape				17 Char./Sec.						10 Char./Sec.
	Magnetic Tape	15,000 Char./Sec.			430 Char./Sec.				25,000 Char./Sec.	6,000 Char./Sec.	
	Typewriter				8 Char./Sec.	10 Char./Sec.	24 Char./Sec.		7 Char./Sec.		10 Char./Sec.
	High Speed Tape Punch				60 Char./Sec.				50 Char./Sec.	60 Char. Sec.	
	Memory Drum Speed	12,500 R.P.M.	6,500 R.P.M.		1800 R.P.M.	3600 R.P.M.			6000 R.P.M.		3600 R.P.M.
	Special Features	Buffer Storage Parity Bit Check	Parity Bit Check	Pin Boards Automatic Checking	108 Word Buffer Ease in Double Precision	Alpha Numeric Control	Pin Boards	Portable Built-in Echo Checking Floating Point Decimal Display	32 Immediate Access Registers		1 Index Register
	Clock Frequency	125 K.C.									
	MEMORY Type	Magnetic Drum	Magnetic Drum	Vacuum Tube	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum
	Word Capacity	2000	84	120	2160	4096	220	4096	8192	4080	8192
	Digits per Word	10 Decimal	10 Decimal	10 Decimal	28 Bits – 7 Decimal	32 Bits – 9 Decimal	12 Decimal	40 Bits	32 Bits – 9 Decimal	10 Decimal	32 Bits – 9 Decimal
	Program Storage	Complete Drum	Complete Drum	Use Plug Boards	Part of Drum	All of Drum	Pin Boards				
	Efficiency of Programming	High	High		High in Machine Language Low in Intercom	Low Due to A Limited Number of Commands	Low Due to A Limited Number of Commands				
	PHYSICAL FEATURES Weight	6000 lbs.	750 lbs.		965 lbs.	800 lbs.		200 lbs.	3400 lbs.		
	Size	60 × 25 × 30 62 × 30 × 71 62 × 30 × 71 = 192.5 Ft.³	25 × 40 × 53 = 30.7 Ft.³		23 × 27 × 61 = 30.5 Ft.³	26 × 33 × 44 = 21.8 Ft.³	60 × 38 × 42 = 55.5 Ft.³	23 × 21 × 16.5 = 4.7 Ft.³	84 Ft.³		Large
	Tubes				180 Tube Packages	113 Tubes		All Transistorized			
	Diodes				300 Diode Packages	1350 Diodes					
	POWER Voltage	208 V. or 230 V ± 10%	105 – 130 V.	220 V.	115 ± 10 V.	115 V.	110 V.	115 V.			115 V. & 230 V.
	Amperage	100 Amps.	16 – 20 Amps.		45 Amps.	13 Amps.		3 Amps			30 Amps.
	K.W.	177 K.V.A.	2.2 K.W.	8 K.V.A.	3.8 K.V.A.	1.5 K.W.		0.4 K.W.	5 K.V.A.	16.5 K.V.A.	5 K.V.A.
	Cycle	60 Cycle A.C.	60 Cycle A.C.		60 Cycle A.C.	60 Cycle A.C.		50 – 60 Cycle			
	Phase	3 Phase	Single Phase			Single Phase		Single Phase	Three Phase		
	TYPE Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose
	Mechanism	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic Digital	Electronic Digital	Electronic Digital	Electronic Digital

									6000 R.P.M.		3600 R.P.M.
ATIONS	Special Features	Buffer Storage Parity Bit Check	Parity Bit Check	Pin Boards Automatic Checking	108 Word Buffer Ease in Double Precision	Alpha Numeric Control	Pin Boards	Portable. Built-in Echo Checking Floating Point Decimal Display	32 Immediate Access Registers		1 Index Register
	Clock Frequency	125 K.C.									
	MEMORY Type	Magnetic Drum	Magnetic Drum	Vacuum Tube.	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum	Magnetic Drum
	Word Capacity	2000	84	120	2160	4096	220	4096	8192	4080	8192
	Digits Per Word	10 Decimal	10 Decimal	10 Decimal	28 Bits – 7 Decimal	32 Bits – 9 Decimal	12 Decimal	40 Bits	32 Bits – 9 Decimal	10 Decimal	32 Bits – 9 Decimal
	Program Storage	Complete Drum	Complete Drum	Use Plug Boards	Part of Drum	All of Drum	Pin Boards				
	Efficiency of Programming	High	High		High in Machine Language Low in Intercom	Low Due to A Limited Number of Commands	Low Due to A Limited Number of Commands				
	PHYSICAL FEATURES Weight	6000 Lbs.	750 Lbs.		965 Lbs.	800 Lbs.		200 Lbs	3400 Lbs.		
	Size	60×25×50 62×30×71 62×30×71 = 192.5 Ft.^{3}	25×40×53 = 30.7 Ft.^{3}		23×27×61 = 30.5 Ft.^{3}	26×33×44 = 21.8 Ft.^{3}	60×38×42 = 55.5 Ft.^{3}	23×21×16.5 = 4.7 Ft.^{3}	84 Ft.^{3}		Large
	Tubes				180 Tube Packages	113 Tubes		All Transistorized			
	Diodes				300 Diode Packages	1350 Diodes					
	POWER Voltage	208 V. or 230 V ∓ 10 %	105 – 130 V.	220 V.	115 ± 10 V.	115 V.	110 V.	115 V.			115 V. & 230 V.
	Amperage	100 Amps.	16 – 20 Amps.		45 Amps.	13 Amps.		3 Amps			30 Amps.
	K.W.	17.7 K.V.A.	2.2 K.W.	8 K.V.A.	3.8 K.V.A	1.5 K.W.		0.4 K.W.	5 K.V.A	16.5 K.V.A	5 K.V.A.
	Cycle	60 Cycle A.C.	60 Cycle A.C.		60 Cycle A.C.	60 Cycle A.C.		50 – 60 Cycle			
	Phase	3 Phase	Single Phase			Single Phase		Single Phase	Three Phase		
	TYPE Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose	General Purpose
	Mechanism	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic	Electronic
	Analogue or Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital	Digital
	Instruction Type	1 + 1 Address	1 Address	3 + 1 Address	Mod. 2 Address	Single Address		Single Address	3 Address	Single Address	3 + 1 Address
	Arithmetic System	Fixed Point	Floating Point	Fixed Point	Fixed Point	Fixed Point		Fixed or Floating Point	Fixed or Floating Point	Fixed or Floating Point	
	Internal No. System	Decimal	Decimal	Binary	Binary	Binary	Decimal	Binary	Binary	Binary Coded Dec	Binary
	Program	Stored Program	Stored Program	Stored Program	Stored Program	Stored Program	Stored Program	Stored Program	Stored Program	Stored Program	Stored Program
GENERAL	**GENERAL** Program Ease	Easy	Easy	Easy	Difficult	Easy	Easy	Easy	Difficult ?		Difficult
	No. of Built-in Operations	89	43	16	84	16	29	50	2^{14}	83	86
	When Introduced	Dec., 1954	June, 1958	1942 ?	July, 1955	Late 1955	Approx. 1950	Fall, 1958	1959	1954	
	Wait for Delivery	10 Months			3 Months	3 Months	1 Month		7 – 9 Months		
	No. in Service as of July/58	1000	Few	1200	130	150	175	0	None in Canada or the U.S.	100	36
	Nearest Serviceman	Supplied With Installation	Toronto		Calgary	Saskatoon, Regina? Calgary		California	Montreal		
	Nearest Relief Equipment	Toronto	Toronto		Winnereg, Calgary	Edmonton, Calgary, Saskatoon, Bismark		California	Montreal		
	Highway Users, Depts	26	1	8	2	1	None	None	None	None	None
	Consultants	Many	No	Few	Many	Several			None in Canada or the U.S.		Several
	Experience	Good	None	Good	Good	Good		None	Limited		Good
ROUTINE TIMES	**SUBROUTINE** Sin x					5×10^{-7} 0.26 Sec	10^{-7} 4.5 Sec	10" 0.25 Sec	0.10 Sec		
	Cos x					5×10^{-7} 0.26 Sec	10^{-7} 4.5 Sec	10" 0.25 Sec	0.10 Sec		
	$\sqrt{n}$	10^{-5} 0.152 Sec.				10^{-8} 0.62 Sec	10" 117 Sec	10" 0.0194 Sec	0.05 Sec		
	Arc Tan n					5×10^{-7} 0.32 Sec	2×10^{-6} 6.0 Sec	10" 0.32 Sec.	0.10 Sec.		
	K^x					5×10^{-8} 0.27 Sec.					
	$\text{Log}_n x$					5×10^{-8} 0.27 Sec	5×10^{-5} 5 Sec	0.30 Sec	0.10 Sec		
	Arc Sine x					5×10^{-7} 0.36 Sec	1×10^{-7} 5 Sec		0.10 Sec		
	Arc Cosine x					5×10^{-7} 0.36 Sec	1×10^{-7} 5 Sec		0.10 Sec		
	e^u						5×10^{-6} 6 Sec.				
	e^{-u}						3×10^{-5} 8 Sec				
	Floating Point Matrix Inversion								0.10 n^3 Sec		
	ODD HIGHWAY PROGRAMS Traverse Per Course	1.5 Sec.									
	Contour Interpolation	16 Readings 5' Interval 4 Sec/Section									
	Conversion of Slope Topography	16 Reading 5.6 Sec/Section									

① These Figures are Approximate and May Not Include Sales Tax and Duty.

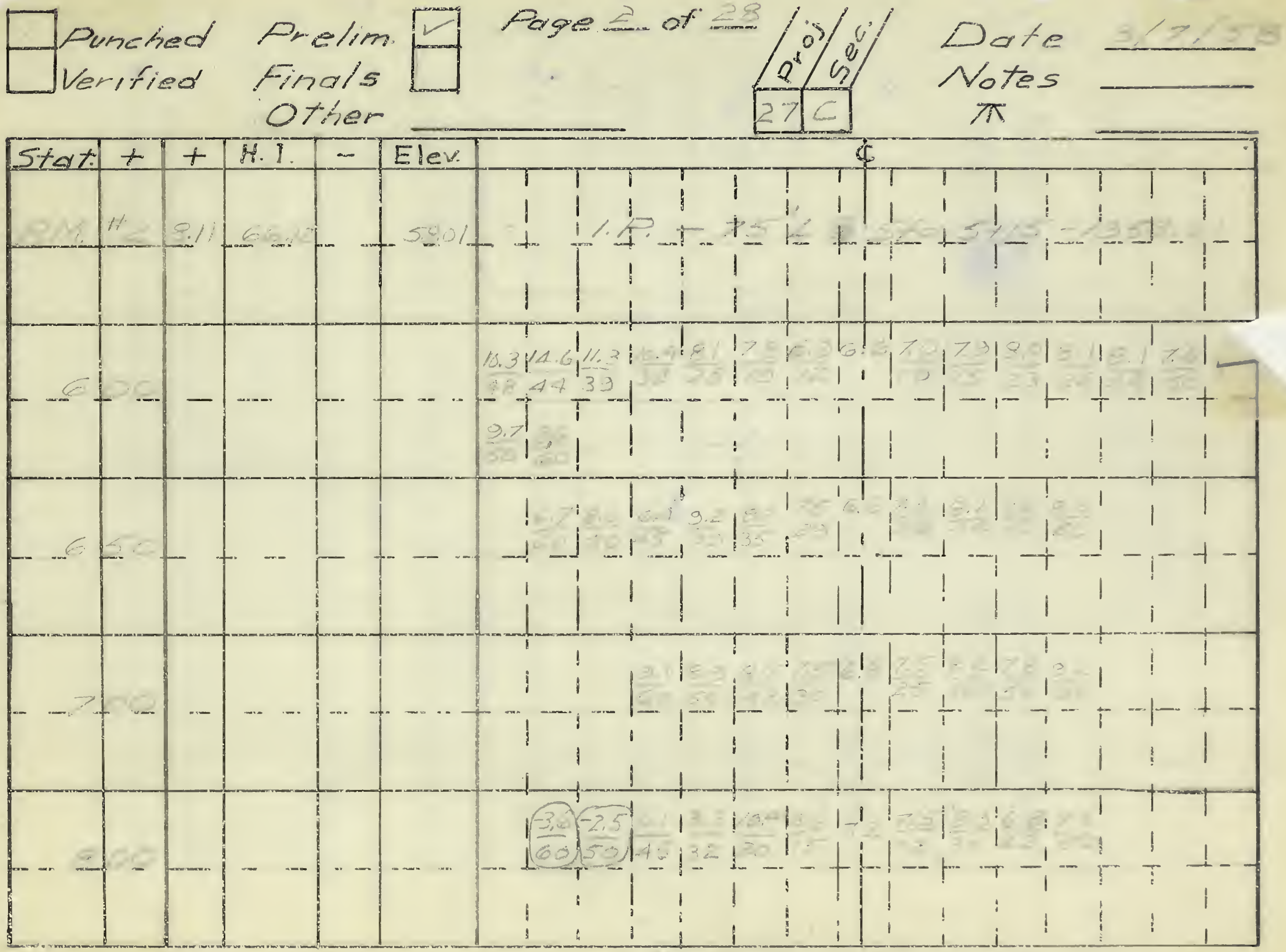
② This Does Not Include Maintenance.

FLOW DIAGRAM OF COMMUNICATION BETWEEN DIVISION OFFICES AND CENTRAL COMPUTER UNIT FOR DESIGN EARTHWORK CALCULATIONS


DIVISION OFFICES
CENTRAL COMPUTER UNIT
SURVEY PARTY COMPLETES FIELD SURVEY.
MAIL DUPLICATE COPY
CROSS-SECTION TAPES PREPARED AND STORED.
GROUND PROFILE PLOTTED AND TRIAL GRADES SELECTED.
MAIL OR PHONE
QUANTITIES FOR TRIAL GRADES COMPUTED. SUMMARIES PREPARED.
MAIL OR PHONE
FIELD CHECK ON TRIAL GRADES.
FINAL GRADE SELECTED.
CROSS-SECTION REFINEMENTS DECIDED UPON.
MAIL
FINAL QUANTITIES COMPUTED.
GRADE AND FINAL CALCULATION RECORDS PREPARED.
MAIL
PLANS COMPLETED.

FROM THE PROCEDURE USED BY THE ILLINOIS DIVISION OF HIGHWAYS

FIG. 4



☐ Punched Prelim. ☑
☐ Verified Finals ☐
Other ____________

Page 2 of 28

Proj	Sec.
27	C

Date 3/7/58
Notes ____________
π

Stat.	+	+	H.I.	−	Elev.	℄
B.M.	#2	8.11	66.12		58.01	I.P. — 75' Lt. [illegible]
600						10.3/48 14.6/44 11.3/33 [illegible] 6.8 [illegible] 9.7/55 [illegible]
650						[illegible] 9.2/32 [illegible]/35 [illegible] 6.8 [illegible]
700						[illegible] 7.5/25 [illegible]
800						−3.8/60 −2.5/50 [illegible]/46 [illegible]/32 [illegible]/20 [illegible] 7.5 [illegible]

Certified Correct ____________ Engineer

Fig. 5

U. S. DEPARTMENT OF COMMERCE

BUREAU OF PUBLIC ROADS
Office of Operations
Division of Development
Washington, D.C.

1. Partial List of Available Programs in Highway Engineering

ELECTRONIC COMPUTER PROGRAM LIBRARY MEMORANDUM NO. 4

November 1958

The Bureau of Public Roads' Electronic Computer Program Library was established by the Federal Highway Administrator to serve as a central point for the receipt and distribution of computer programs developed for use in the highway field, and the dissemination of collateral information, in order to minimize duplication and to expedite the development of electronic computer applications. Each program received for the library is adjusted to remove terminology peculair to the computer for which it was developed and to assure completeness and clarity. The final library version of the program, expressed solely in English and mathematical terms, can then be coded for use with any digital computer.

This is the fourth of a series of memoranda issued periodically to provide information on programs received for

the Bureau's program library, programs available in library form and other pertinent developments. It contains all the programs listed in earlier memoranda as well as those received or converted to library form since those memoranda were prepared.

Inquiries regarding the availability of these programs should be addressed to the Division of Development, Office of Operations, Bureau of Public Roads, Washington 25, D.C.

a. Electronic Computer Programs Available in BPR Library Form

(i) Program BPR E-1

Earthwork Quantities - developed in Illinois Division of Highways. (Originally developed for Bendix G-15)

This is a design program arranged as a series of 8 subroutines which may be modified to meet requirements different from those of Illinois. The subroutines are:

(1) Crown Elevations

(2) Template Simulation

(3) Slope Selection

(4) Slope Stake Coordinates

(5) Trapezoid Coordinates for Area Computations

(6) Areas

(7) Shrinkage

(8) Volumes and Cumulative Volumes

The program in its present form is used in the design of undivided roadways and of divided roadways in which the two pavements, although separated by a median, have the same profile grades. A modification of this program, to accomodate grades that are parallel (not necessarily at the same level), has been completed by the Illinois Division of Highways but has not yet been converted to library form.

(ii) Program BPR E-2

Earthwork Quantities - developed in Missouri Highway Department. (Originally developed for IBM-650)

This is a design program which is used for both undivided and divided roadways. In addition, it computes rock excavation quantities separately from earth excavation quantities. The program is divided into 7 segments of computation as follows:

(1) Station Sequence Check

(2) Conversion of Rod Readings to Elevations

(3) Computation of Template Points and Corrections for Superelevation and Variable Width

(4) Slope Selection and Slope Stake Coordinates

(5) Total Areas

(6) Earth and Rock Areas

(7) Shrinkage, Volumes and Cumulative Volumes

(iii) Program BPR E-3

Borrow Pit Quantities - developed in Bureau of Public Roads, Division of Development. (Developed directly in library form)

This program permits the computation of the volume of material removed from a borrow pit directly from preliminary and final survey notes with a minimum of processing. It can be used to determine either progress payments or final payment for "borrow" and also to estimate the quantity of material available from a proposed borrow pit based on borings or other methods of subsurface exploration.

(iv) Program BPR HA-1

Spiral Coordinates - developed by Vogt, Seaman and Associates, Engineers-Architects, Cincinnati, Ohio. (Originally developed for Bendix G-15)

This program is used to compute the coordinates of any point on a spiral and/or the coordinates of any point on a radial line through a point on the spiral.

(v) Program BPR S-1

Reduction of Triaxial Test Data - developed in Texas Highway Department. (Originally developed for IBM-650)

This program is used for the reduction of data from the triaxial sheer test. The computer produces the data for plotting the stress-strain diagram and for determining the choesion and the coefficient of internal friction either analytically, or graphically through the use of Mohr's stress circles.

(vi) Program BPR ST-1

Continuous Steel Beam Bridge Design - developed in Bureau of Public Roads Division of Development. (Developed directly in library form)

This program applies to continuous steel beam bridges of 3, 4 or 5 equal or unequal spans for which wide flange beams are appropriate. Given the number of spans, span lengths, loading and allowable unit stress, the program provides for the computation of the sizes of interior and exterior beams required and the number and sizes of cover plates needed over the piers.

(vii) Program BPR ST-2

Computation of Continuous Beam Characteristics - developed in Nebraska Department of Roads. (Originally developed for IBM-650).

This program is used to determine carry-over factors, stiffness factors and fixed-end moments for a continuous beam which is part of a structure or frame, given the span lengths and moments of inertia. The continuous beam is solved a span at a time and each span is treated as an individual problem.

(Viii) Program BPR ST-3

Skewed Bridge Geometry (Straight Alignment) developed in Texas Highway Department. (Originally developed for IBM-650)

This program is used for finding the station of any desired point on any working line; the skew distance along the line to the point; the elevation at the point for finished

grade, also for top of capelevation for the point if it is a point over a beam support; and the length and slope of the beam between a corresponding point on a previous working line and the point, if it is a point where top of cap elevation is computed. The program thus provides most of the dimensions needed for the design and construction of bridges with skewed bents, constant roadway widths and straight roadway alignment.

(ix) Program BPR ST-4

Analysis of Rectangular Reinforced Concrete Columns - developed by Richardson, Gordon and Associates, Consulting Engineers, Pittsburgh, Pennsylvania. (Originally developed for Bendix G-15)

This program is used to compute the maximum concrete and steel stresses in a rectangular or square reinforced concrete

column subjected to axial load and one-way or two-way bending.

(x) Program BPR ST-5

Composite Beam Analysis and Design - developed by Michael Baker, Jr., Inc. Consulting Engineers, Rochester, Pennsylvania (Originally developed for IBM-650)

This program is used for the analysis or design of simply supported composite concrete slab and rolled steel section beams in accordance with the 1957 AASHO Standard Specifications for Highway Bridges. It was developed primarily for the compilation of design tables for composite beams but is equally applicable to the analysis or design of any simply supported composite concrete slab and steel stringer bridge deck.

(xi) Program BPR SU-1

Right-of-Way Traverse and Area Computation - developed in Nebraska Department of Roads. (Originally developed for IBM-650)

This program is divided into two parts, first the computation of lengths and bearings for each course of a right-of-way parcel for use in preparing the deed description, and second the computation of the area of the parcel. Given data consists of an initial bearing, and the stations and centerline or baseline offsets of the corners of right-of-way takings along the project. The program provides for the computation of length, bearings and areas for successive right-of-way parcels along a proposed project as a continuous computer operation.

(xii) Program BPR T-1

Forecasting Interzonal Traffic Movements (Fratar Method) - developed in Bureau of Public Roads, Division of Development. (Originally developed for IBM-705).

This program uses a system of successive approximations to project present interzonal

traffic volumes to some future time based on individual growth factors for each zone. It consists of three major parts for performing the computations on:

(1) Conventional punched card equipment and externally programmed electronic computers with limited storage.

(2) Intermediate size electronic computers.

(3) Large high-speed electronic computers.

(xiii) Program BPR T-2

Preparation of Data for a Trip Desire Contour Chart - developed in California Division of Highways. (Originally developed for IBM-650)

This program is used to compute the desire-line trip density data necessary to plot a trip desire contour chart for origin and destination survey data. The survey area is processed a swath at a time until the whole area has been covered.

The program embodies the principles originally set forth in a paper, "The Coordinate Method of O and D Analysis" by K.A. MacLachlan, of the California Division of Highways, presented at the 29th Annual Meeting of the Highway Research Board, December, 1949.

(xiv) Program BPR T-3

W-6 Loadometer Truck Weight Table - developed in California Division of Highways. (Originally developed for IBM-650)

This program is used to edit and analyze loadometer survey data and to compile a listing of commercial vehicle weights, axle loads, axle spacings and load limitation violations.

(xv) Program BPR T-4

Traffic Assignment - developed by Edwards and Kelcey, Engineers and Consultants, Newark, New Jersey. (Originally developed for IBM-650)

This program is used to determine the traffic volumes that would be attracted to a proposed freeway using Origin and Destination Survey Data. The output data is in sufficient detail to provide all necessary volumes for interchange ramp design, number of freeway traffic lanes and cost benefit studies. The program uses the American Association of State Highway Officials' traffic diversion curve. It may be adapted to any time ratio diversion curve.

(xvi) Program BPR T-5

Speed Check Analysis - developed in Washington State Department of Highways. (Originally developed for IBM-650)

This program is used to analyze traffic speed checks for from one to six vehicle type classifications with provision for a range of speeds from 5 to 80 miles per hour.

b. Other Programs Received in Library but not Available in BPR Library Form at this Time

Contributor	Subject	Computer Used
Arizona Highway Department	Vertical Alignment	Univac 120
"	Earthwork (Prelim.)	"
"	Earthwork (Staked)	"
"	Horizontal Alignment	"
"	Traverse Coordinates	"
"	Bridge Deflections	"
"	Least Squares Trend Line	"
California	Earthwork (Prelim. & Final)	IBM 604
Division of	Earthwork (Prelim. & Final)	IBM 650
Highways	Traverse Computation	"
"	Traverse Adjustment	"
"	Three-centered Curves	"
"	Composite Beam Design	"
"	Traffic Assignment	"
"	Reinforcing Steel Quantities	"
"	Four Factor Quantity Computations	"
"	Approximations of Future Trip Transfers (Fratar Method)	"

Contributor	Subject	Computer Used
California Division of Highways	General Freeway Assignment	IBM 650
	San Diego Freeway Assignment	"
Connecticut Highway Department.	Plane Coordinate Traverse Computation	Univac 120
	Borrow Bank Computations	"
"	Earthwork (Prelim.)	"
"	Permanent Traffic Recorder Counts	"
Georgia Highway Department	Geometry of Skewed Bridges on Curves	IBM 650
Idaho Department of Highways	Earthwork (Prelim. and Final)	Univac 120
Illinois Division of Highways	Earthwork Quantities (Dual Highway Design)	Bendix G-15

Contributor	Subject	Computer Used
Illinois Division of Highways	Earthwork Quantities (Widening)	Bendix G-15
"	Earthwork Quantities (Final for Roadways or Borrow Pits)	"
"	Azimuth Determination from Sun Observation	"
"	Embankment Stability Design	"
"	Bridge Deck Elevations	"
Indiana Highway Department	Profile Grades	IBM 650
	Ditch Grade Analysis	"
Maryland Roads Commission	Earthwork Quantities (Prelim.)	Univac 120
"	Traverse Computation	"
"	Soil Constants	"

Contributor	Subject	Computer Used
Michigan Highway Department	Earthwork (Prelim.)	Bendix G-15
	Vertical Alignment	"
"	Traverse Closure	"
Minnesota Department of Highways	Earthwork (Design)	Univac 120
Missouri Highway Department	R.C. Box Culvert Design	IBM 650
Nebraska Department of Roads	Earthwork (Final)	IBM 650
	Bridge Deflections	"
"	R.C. Box Culvert Design	"
"	Roadway Design	"
"	Template and Grades	"
"	Rectangular R.C. Column Analysis	"
"	Extension of Continuous Beam Characteristics Program	"

Contributor	Subject	Computer Used
Ohio Department of Highways	Design Template	IBM 650
	Superelevation	"
"	Road Design	"
"	Rod Reading Conversion	"
"	Survey Traverse Computation	"
"	Cut & Fill (With Seeding Areas)	"
"	Bid Analysis & Tabulation	"
Oklahoma Highway Department	Bid Checking and Tabulation	Univac 120
	Geometry of Skewed Bridges on Curves	"
Oregon Highway Department	Two-Span Continuous Bridge Analysis	IBM 650
"	Three-Span Continuous Bridge Analysis	"
"	Four-Span Continuous Bridge Analysis	"
"	Five-Span Continuous Bridge Analysis	"

Contributor	Subject	Computer Used
Oregon Highway Department	Beam Deflections	IBM 650
	Dead Load plus Live Load Moments	"
Texas Highway Department	Geometry of Skewed Bridges on Curves	IBM 650
"	Earthwork Quantities (Prelim.)	"
"	Earthwork Quantities (Final)	"
"	Field Note Reduction and Construction Staking	"
Washington Department of Highways	Earthwork Line Shift	IBM 650
	Maximum Density Granular Materials	"
"	Moment Distribution	"
"	Slopes and Deflections in Finite Beams on Elastic Foundations	"
"	Moments in Finite Beams on Elastic Foundations	"

Contributor	Subject	Computer Used
Washington Department of Highways	Forecasting Zonal Traffic Volumes	IBM 650
	Slope Stability Analysis	"
"	Suspension Bridge Analysis	"
"	Moment Distribution & Influence Line Calculations	"
Bureau of Public Roads	Earthwork (Staked)	IBM 650
	Traverse	"
"	Clearing and Grubbing	"
"	Slope Topography	"
"	Contour Interpolation	"
"	Equipment Cost Accounting Portion of AASHO Uniform Accounting System	"
Michael Baker, Jr., Inc.	Bearing from Polaris	IBM 650
	Bar Schedule Steel Computations	"
"	Highway Grade Profile	"
"	Earthwork (Design)	"

Contribution	Subject	Computer Used
Michael Baker, Jr., Inc.	Geometrics for Skewed Bridges on Horizontal Circular Curves	IBM 650
"	Cross Section Note Reduction	"
"	Bridge Deflections	"
"	Stadia Note Reduction	"
Alfred Benesch & Associates	Reinforcing Steel Quantities	Bendix G-15
Consoer, Townsend & Associates	Screed & Form Elevations	Bendix G-15
	Slab Fillet Determination	"
DeLeuw, Cather & Company	Retaining Wall Design	Bendix G-15
	Roadway Elevations for Bridges on Circular Curve	"
"	Influence Lines (2-span)	"
"	Traverse Computation	"
"	Loop Interchange Computation	"

Contribution	Subject	Computer Used
Edwards & Kelcey	Deflection Angles for Horizontal Curves	Bendix G-15
"	Horizontal Curve Data	"
Enelco, Ltd.	Influence Lines for 3-span Frame with two Integral Legs	"
Gannett, Fleming, Corddry & Carpenter	Bridge Geometry (On Tangent)	IBM 650
Goodkind & O'Dea	Coordinate Calculations	Burroughs E-101
J.E. Greiner, Inc.	Coordinates of the Path of a Point on a Rolling Lift Bascule Leaf	Bendix G-15
"	Vertical Alignment	"
Harley, Ellington & Day	Steel Column Design	Bendix G-15
	Grades for Independent Ditch	"
"	Abutment Design	"

Contribution	Subject	Computer Used
Lockwood, Kessler & Bartlett	Bridge Bearing Elevations	Bendix G-15
	Areas by Coordinates	"
"	Areas of Sectors and Segments	"
"	Composite Beam Design	"
"	Areas of Polygon, Sector and Segment	"
McElhanney, McRae, Smith & Nash and Computing Devices of Canada, Ltd.	Earthwork Quantities	"
John F. Meissner Engineers, Inc.	Three-Point Problem Solution by Runge's Method	"
"	Foresection from Coordinate Data	"
Palmer & Baker Engineers, Inc.	Three-Column Rigid Frame Pier Analysis	"

Contribution	Subject	Computer Used
Parsons, Brinckerhoff, Hall & MacDonald	Composite Beam Design	Bendix G-15
	Bridge Camber	"
	Stringer Layout Geometry	"
"	Highway Profiles	"
"	Alignment Subroutines	"
Richardson, Gordon & Associates	Continuous Beam Influence Lines	"
	Job Costs	"
"	Beam Deflections	"
"	Cantilever Beam Deflections	"
"	Shear and Moment Influence Lines for Intermediate Panels Between Supports for Continuous Beam Design	"
Tudor Engineering Company	Four-Span Rigid Frame Bridge Analysis	"

Contribution	Subject	Computer Used
Vogt, Ivers,	Pier Analysis (Mom. Dist.)	Bendix G-15
Seaman &	Pier Analysis (Slope-Def.)	"
Associates	Bridge Reinf. Steel Quantities	"
"	Circular R.C. Column Analysis	"
"	Earthwork Quantities (Prelim.)	"
"	Fixed Arch Analysis	"
"	Flow in Open Channels	"
J. Stephen Watkins	Beam Grid Elevations	"
Wilson & Company	Circular R.C. Column Analysis	"
"	Horizontal Curve Computation	"
"	Computation of Pile Loads	"
"	Beam Deflections	"
"	Variable Dimensions of Two-Centered Compound Curves	"
"	Interchange Ramp Computations	"

Contribution	Subject	Computer Used
Bendix Computer Division	Backwater Computation including Bridge Loss	Bendix G-15
City of Chicago	Urban Runoff Computation	"
Computing Devices of Canada, Ltd.	Geodetic Triangulation Computation	"
U.S. Army, Corps of Engineers	Hydraulic Backwater Computation	IBM 650
	Spiral Curve Computation	Bendix G-15
"	Channel L-Wall Design	"
"	Channel U-Wall Design	"
"	Conversion of Coordinates to Distance and Bearing	"
"	Traverse Intersection	"
"	Statistical Analysis for Quality Control (Soil Density and Moisture Control)	"

Contributor	Subject	Computer Used
Electronic Calculating Service	Traverse and Area Computation	Bendix G-15
"	Arc Length, Sector Area & Tangent Distance	"
Massachusetts Institute of Technology	Borrow Pit Quantities	IBM 650
	Digital Terrain Model System	"
	a. Terrain Data Edit	
	b. Basic Horizontal Alignment	
	c. Even Station Interpolation	
	d. Parallel Offset Alignment	
	e. Special Alignment Geometry	
	f. Basic Vertical Alignment	
	g. Highway Profile Geometry	
	h. Preliminary Earthwork	

2. Questionnaire on Electronic Computers

The following Questionnaire was sent to each of the State or Provincial Highway Departments in the United States and Canada. The results of this questionnaire are contained in Fig. 1

2. Questionnaire on Electronic Computers

Does your department make use of electronic computer techniques for highway engineering calculations?

If so, answer Part I

If not, answer Part II

Part I

a. Do you:

(i) lease?......................% of computer time

(ii) make use of consultants?...%of computer time

(iii) own your own computer?.......................

b. What make of computer do you use?.......................

c. How long have you used these techniques?.........months

d. Are the computer techniques used in the following fields:

(i) Design earthwork quantity calculations?

(1) ....(yes or no)

(2) Average volume of calculations completed by computer per month ....mile

(3) What percentage of design earthwork calculations are presently being carried out by the electronic computer?............%

(4) What is the average cost which you estimate for calculation of one mile of design earthwork quantities of two-lane highway or equivalent by electronic computer techniques?...............................

(5) What is the average number of sections per mile which you experience?...............

(6) What is the average number of points per section?...............................

(ii) Final pay earthwork quantities:

(1) ....(yes or no)

(2) Average volume of calculations completed by computer per month?...............months

(3) What percentage of your final pay quantity calculations are presently being carried out on the electronic computer?...........

(4) What is the average cost which you estimate for calculation of one mile of final pay earthwork quantities of two lane highway or equivalent

by electronic computer techniques:........

(iii) Structural design calculations:

(1) ....(yes or no)

(2) Percentage of total done by computer.......%

(iv) Traffic engineering and planning:

(1) ....(yes or no)

(2) What percentage of the total calculations carried out in this field are being done on the computer?...........................%

(v) Hydrology and hydraulics:

(1) ....(yes or no)

(2) What percentage of the total calculations carried out in the field are being done on the computer?.........................%

(vi) Photogrammetry:

(1) Have you integrated your electronic computer to work directly from photographic surveys, thereby eliminating much of the field surveying required?...............(yes or no)

(vii) Survey calculations: such as -

(1) Traverse problems.........................

(2) Land areas ....

(3) Geometric alignment calculations ....

(4) Other ....

(viii) Other highway engineering problems solved by electronic computer ....

....

e. What computer staff do you have?...........

(i) Director ....

(ii) Programmers.................

(iii) Coders ....

(iv) Machine operators ....

(v) Key punch operators ....

(vi) Others ....

Total computer staff ....

Part II

a. If your department is not now actively engaged in the field are you considering the use of electronic computers to assist

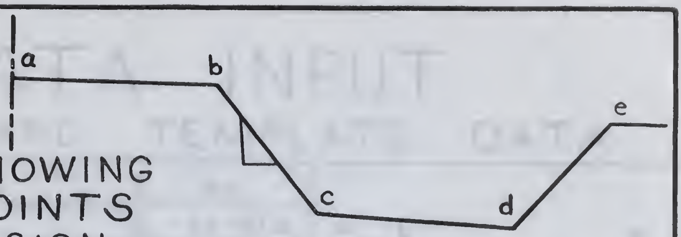
you in your highway engineering calculations?..............

b. Have you undertaken a study on the possible use of Electronic Computer Technieques?...........................

c. Do you have an electronic computer on order?..............

3. Flow Diagrams for Design and Final Earthwork Programs

The following portion of the appendix contains a series of flow charts which the author has prepared for the calculation of design and final earthwork quantities for highways in Saskatchewan. The flow charts illustrate only the general lines which the program will follow. The input and output data for each of the programs has been included to illustrate the potential of the program.



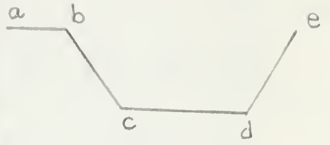
SKETCH SHOWING CONTROL POINTS ON THE DESIGN TEMPLATE OF A GRADED SECTION

Subscript (h) – Horizontal Distance.
Subscript (v) – Vertical Distance (or Elevation of Single Point).
Subscript (s) – Slope.
(*) – Constant Data for One Project.
(C) – Constant for All Jobs in One Province.
(**) – Constant for Several Stations.

PROVINCE	ABREVIATION	SASKATCHEWAN					ALBERTA
HIGHWAY CLASS		B	C	D	E		
½ Top Width. Standard	(a-b)h	25'-30'	VAR 19'-24'	IABL 14'	E 12'	**	VARIABLE
Widening on Curves	Wc	Nil	Nil	Nil	Nil	**	1'-2'
Widening for Slopes Steeper than Standard	Ws	2'	2'	2'	2'	C	1'
Distance Over Which Widening Takes Place		1 Sta.	1 Sta.	1 Sta.	1 Sta.	C	1 Sta.
Crown Slope. Standard.	(a-b)s	30:1	25:1	25:1	25:1	*	– 30:1
Superelevation	e	–12.5:1	VAR –	IABL +12.5:1	E	**	VARIABLE
Side Slope. Standard.	(b-c)s	4:1	4:1	3:1	3:1	*	4:1
Height of Fill at Which Change of Slope is Required.	f_1	10'	10'	6'	6'	*	5.25
(b-c)h Where Height of Fill is Over the Above Limit.	$j_{(1-2)}$	40'	40'	18'	18'	*	21'
Height of Fill at Which the Minimum (b-c)s is Used.	f_2	20'	20'	9'	9'	*	7'
Minimum Side Slope to Use.	s_m	2:1	2:1	2:1	2:1	C	3:1
(c-d) h	(c-d) h	20'-30'	VAR 20'-30'	IABL 15'-25'	E 15'-25'	**	VARIABLE 10'-20'
Ditch Slope. Standard.	(c-d) s	25:1	25:1	25:1	25:1	C	(MAX. 1' DROP) –20:1
Back Slope. Standard.	(d-e) s	(MAY 4:1	VARY 4:1	FOR 3:1	SNOW) 3:1	**	3:1
Maximum Distance (a-e)h Before The Change in (d-e)s is Required. } Except	R		VAR	IABL	E	**	VARIABLE
Minimum (d-e)s	s_2	AS NOR	SPE MALL	CIFIE Y 1	D ½:1	**	NORMALLY 2:1
(a-d) v	D	3'-6'	VAR 3'-6'	IABL 3'-6'	E 3'-6'	**	VARIABLE

DATA INPUT

A. STANDARD TEMPLATE DATA

1. (a-b)h	7. Sm	
2. Ws	8. (c-d)s	
3. (a-b)s	9. (d-e)s	
4. (b-c)s	10. k	
5. f_1	11. S_2	
6. j(1-2)		

B. DESIGN VARIABLES

1. STATION, ELEVATION AND L.V.C. FOR EACH P.I. FOR THE ℄ AND THE DITCHES.
2. STATION AND SUPERELEVATION OF HORIZONTAL CURVE DATA.
3. STATION AND VALUE OF ANY TEMPLATE CHANGES.
4. STATION, "D" AND (a-d)h WHERE THE LATTER DIFFER FROM THOSE OF THE PREVIOUS STATION.
5. STATION AND S.F. WHERE IT DIFFERS FROM THAT OF THE PREVIOUS STATION.
6. STATION OF NEW STRUCTURES WHERE THERE IS "NO FILL".
7. CHAINAGE EQUATION.
8. % GRADE OF THE FIRST TWO GRADES.

C. FIELD NOTE DATA
(FOR EACH STATION)

1. CROSS-SECTION STATIONS.
2. ROD READINGS FOR PRELIMINARY SURVEY.
3. HORIZONTAL DISTANCE TO THE PRELIMINARY POINT.
4. H.I. (IF IT IS DIFFERENT FROM THAT OF THE PREVIOUS STATION.

RANGE OF INPUT

Rod Readings	0 to ± 99.99
Horizontal Distances at Right Angles to ℄	0 to + 999.9
Stationing	0 to + 9,999 + 99.9
Elevation or H. I.	0 to + 9,999.99
Slopes	0 to + 99.9 (Meaning 99.9 : 1.0)
L. V. C.	0 to 9,999
S. F.	0.000 to 9.999

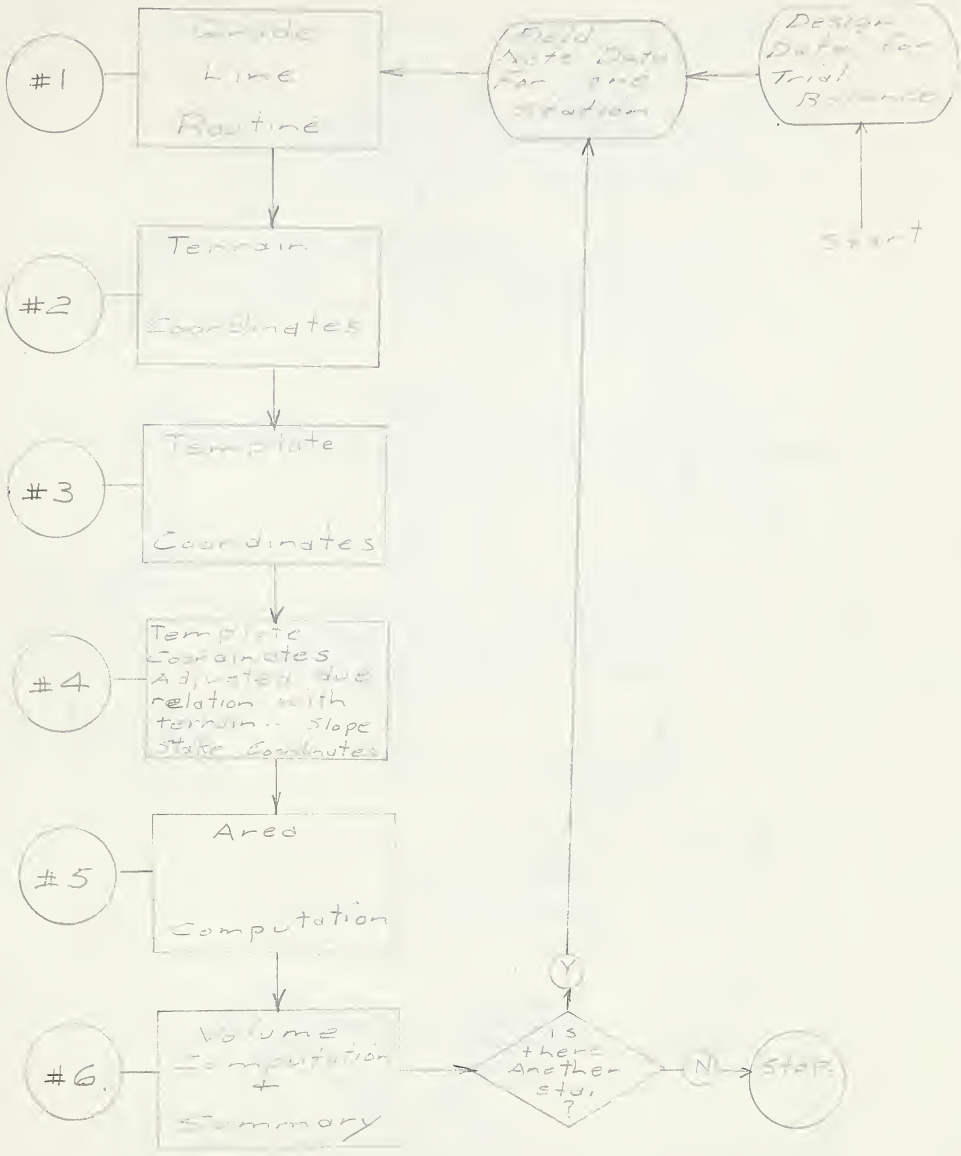
RANGE OF ACCURACY OF RESULTS

	Range	Accuracy
Elevations	0 to 9,999.99	The Nearest Hundredth of a Foot
Horizontal Distances at Right Angles to ℄	0 to 999.9	The Nearest Tenth of a Foot
Slopes	0 to 99.9	The Nearest Tenth of a Foot
End Areas	0 to + 99,999	The Nearest Square Foot
Volumes	0 to ±9,999,999	The Nearest Cubic Yard

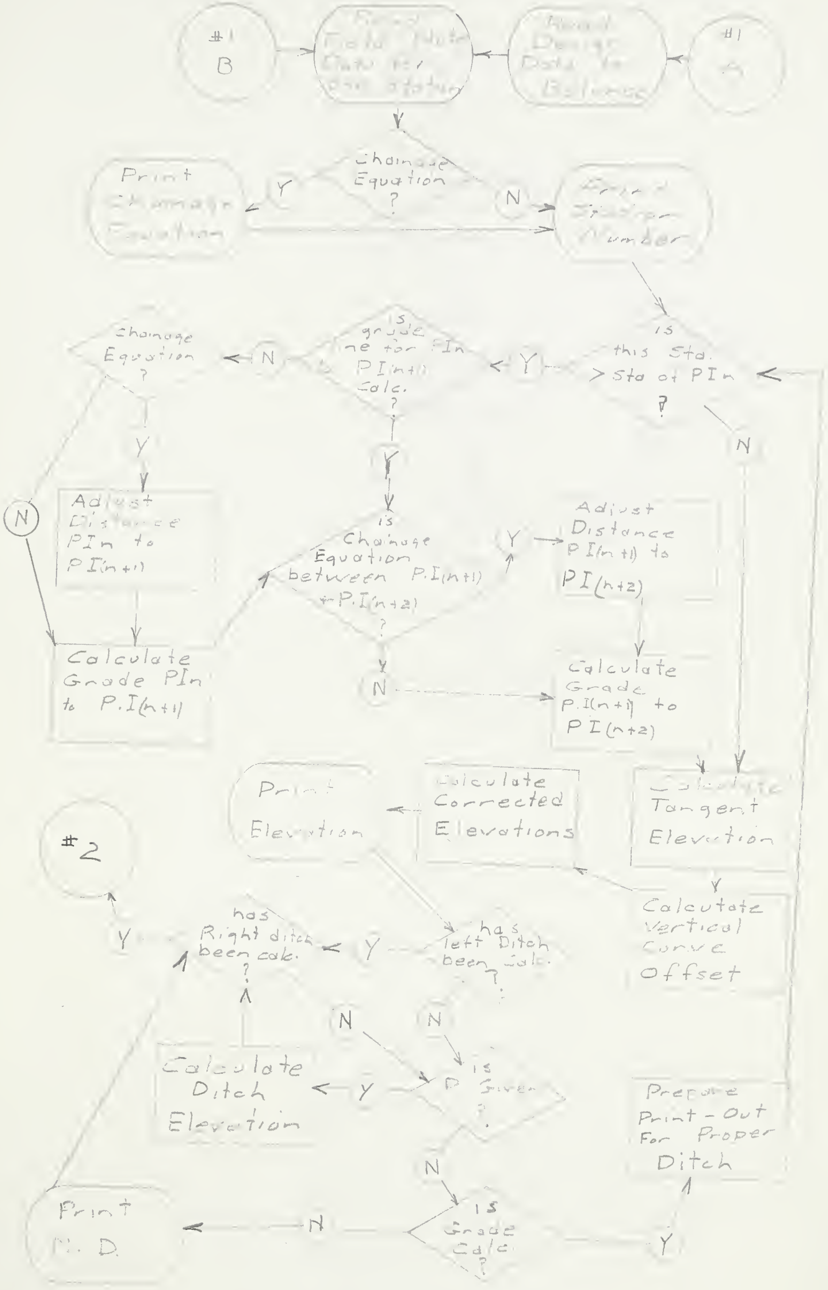
Output

```
STATION      ELEVATION                          SLOPE   STAKE                                     END AREAS         VOLUMES          ACCUMULATED
                                                                                                                                   VOLUMES
                  FT.                      LEFT                             RIGHT                    FT.²                YD.³
          Centre  Left  Right   Side Slope       Back Slope       Side Slope       Back Slope                                Adj.
            Line  Ditch DitchSlope Dist. Elev.Slope Dist. Elev.Slope Dist. Elev.Slope Dist. Elev.  Cut  Fill   Cut    Fill   Fill    Cut     Fill
XXXX.XX.X XXXX.XX XX.XX XX.XX XX.X XXX.X XX.XX XX.X XXX.X XX.XX XX.X XXX.X XX.XX XX.X XXX.X XX.XX XXXXX XXXXX XXXXXX XXXXXX XXXXXX XXXXXXX XXXXXXX
   9.00.0 1602.31 98.31             45.3 02.12       85.3 03.65  2.6  55.2 96.13                    305
  10.00.0 1601.67 97.67             47.1 02.07       87.1 03.72  2.8  50.5 97.33                    239         1008                  1008    1008
  11.00.0 1601.02 97.02             45.7 00.96       85.7 02.16       47.1 98.24                     29    61    496    113    143    1504    1362
  12.00.0 1600.37 96.37 96.37       38.9 98.05       78.9 00.73       40.8 98.11       87;6 02.65    26    66    102    236    296    1606    1168
  Equation of Stations 12 + 25 (Back) = 12 + 75 (Ahead)
  13.00.0 1600.08 95.08 95.08       45.4 99.94       85.4 00.02       42.5 99.63       86.3 00.73   158          170     61     77    1777    1262
```

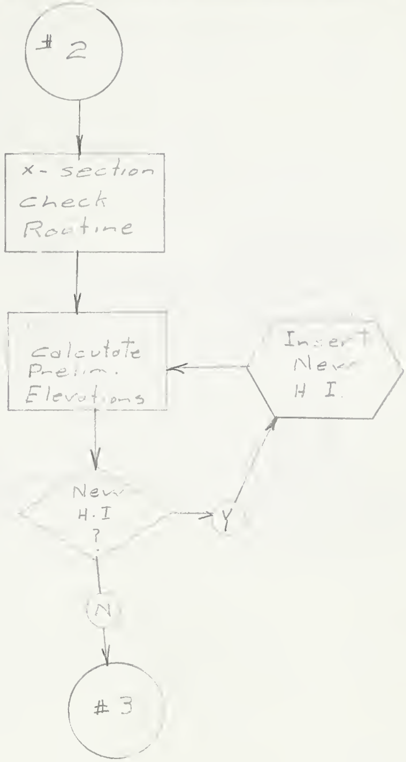
Design Earthwork Computation


Design Data for Trial Balance
Start
Field Note Data for one Station
Grade Line Routine
#1
Terrain Coordinates
#2
Template Coordinates
#3
Template Coordinates Adjusted due relation with terrain.. Slope Stake Coordinates
#4
Area Computation
#5
Volume Computation + Summary
#6.
Is there Another sta. ?
Y
N
Stop

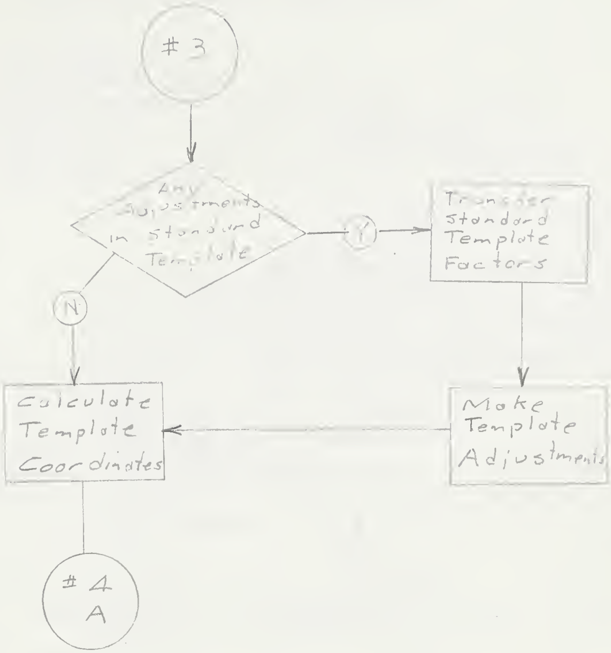
Grade Line Routine D#1


#1 B
Read Field Note Data for one station
Read Design Data for Balance
#1 A
Chainage Equation ?
Y
N
Print Chainage Equation
Print Station Number
is this Sta. > Sta of PIn ?
Y
N
is grade line for PIn PI(n+1) Calc. ?
N
Y
Chainage Equation ?
Y
N
Adjust Distance PIn to PI(n+1)
Calculate Grade PIn to P.I(n+1)
is Chainage Equation between P.I(n+1) + P.I(n+2) ?
Y
N
Adjust Distance P.I(n+1) to PI(n+2)
Calculate Grade P.I(n+1) to PI(n+2)
Calculate Tangent Elevation
Calculate Vertical Curve Offset
Calculate Corrected Elevations
Print Elevation
has left Ditch been calc. ?
Y
N
has Right ditch been calc. ?
Y
N
#2
is D Given ?
Y
N
Calculate Ditch Elevation
is Grade Calc. ?
N
Y
Print N. D.
Prepare Print-Out For Proper Ditch

[illegible] D#2


#2
x-section Check Routine
Calculate Prelim. Elevations
Insert New H.I.
New H.I ?
Y
N
#3

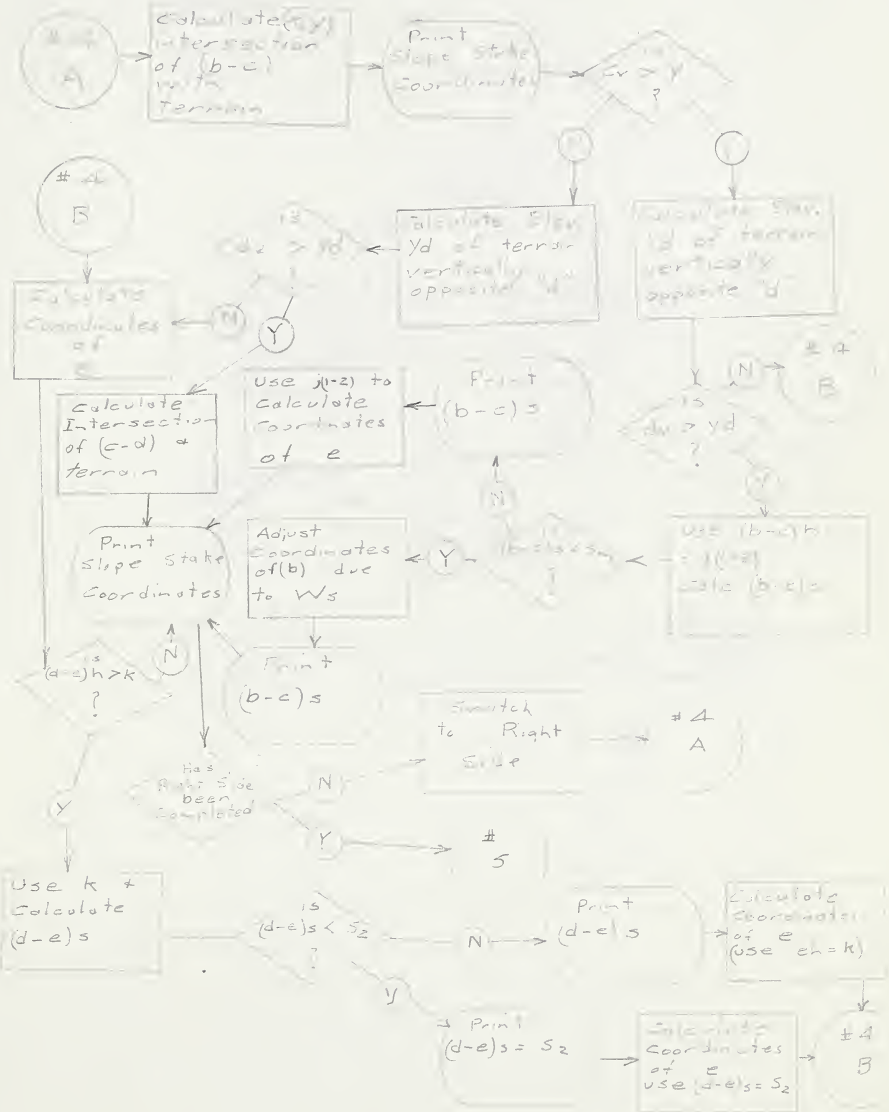
Template Coordinates D#3



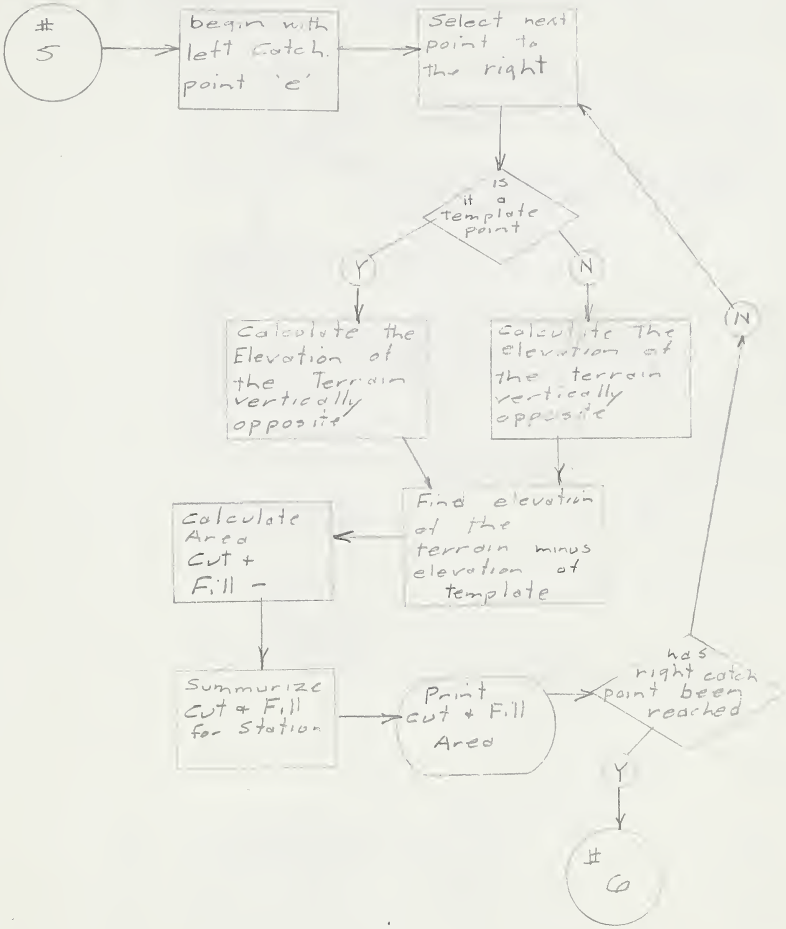
#3
Any Adjustments in standard Template
Y
Transfer standard Template Factors
N
Make Template Adjustments
Calculate Template Coordinates
#4 A

D#4

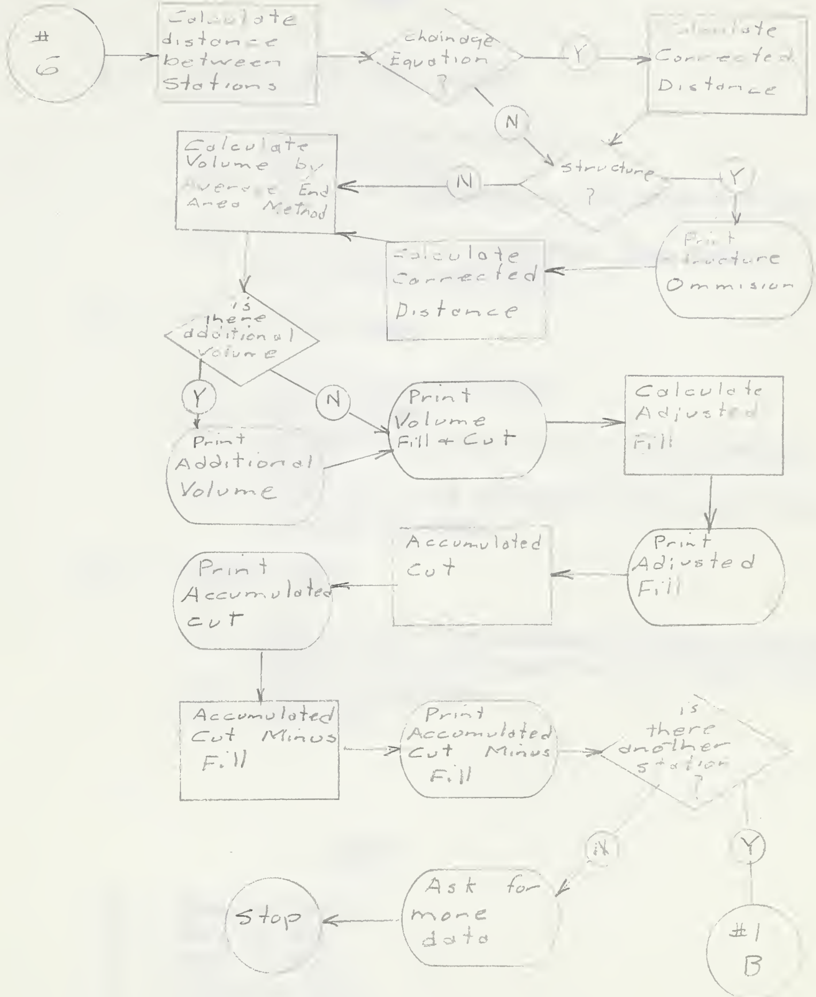
Template Coordinates Adjusted Due to Relation with Preliminary and Slope Stake Coordinates


#4
A
Calculate (x,y) intersection of (b-c) with Terrain
Print Slope Stake Coordinates
is cx > y ?
N
Y
#4
B
Calculate Elev yd of terrain vertically opposite "d"
Calculate Elev. yd of terrain vertically opposite "d"
is cdx > yd ?
Calculate Coordinates of e
N
Y
#4
B
is dx > yd ?
Calculate Intersection of (c-d) & terrain
Use j(1-2) to Calculate Coordinates of e
Print (b-c)s
N
Y
Use (b-c)h = j(1-2) calc (b-c)s
is (b-c)s < s₁ ?
Y
Print Slope Stake Coordinates
Adjust Coordinates of (b) due to Ws
N
is (d-e)h > k ?
Print (b-c)s
Switch to Right Side
#4
A
Has Right Side been Completed
N
Y
#
5
Y
Use k & Calculate (d-e)s
is (d-e)s < S₂ ?
N
Print (d-e)s
Calculate Coordinates of e (use eh = k)
Y
Print (d-e)s = S₂
Calculate Coordinates of e use (d-e)s = S₂
#4
B

Area Computation D# 5


#
5
begin with left Catch. point 'e'
Select next point to the right
is it a template point
Y
N
Calculate the Elevation of the Terrain vertically opposite
Calculate The elevation of the terrain vertically opposite
Find elevation of the terrain minus elevation of template
Calculate Area Cut + Fill −
Summurize Cut + Fill for Station
Print cut + Fill Area
has right catch point been reached
N
Y
#
6

Volume Computation D# 6



#6
Calculate distance between Stations
Chainage Equation ?
Y
Calculate Corrected Distance
N
Structure ?
Y
N
Calculate Volume by Average End Area Method
Print Structure Ommision
Calculate Corrected Distance
is there additional volume
Y
N
Print Additional Volume
Print Volume Fill + Cut
Calculate Adjusted Fill
Print Adjusted Fill
Accumulated Cut
Print Accumulated Cut
Accumulated Cut Minus Fill
Print Accumulated Cut Minus Fill
is there another station ?
N
Y
Ask for more data
Stop
#1 B

FINAL EARTHWORK CALCULATIONS

INPUT

# 1 PRELIMINARY FIELD NOTES

(a) Cross-section stations.
(b) Rod readings.
(c) Horizontal **distance** to the cross-section point.
(d) H. I. (if it is different from that of the previous station).

# 2 FINAL FIELD NOTES

(a) Cross-section station.
(b) Rod readings.
(c) Horizontal distance to the cross-section point.
(d) H. I. (if it is different from that of the previous station).

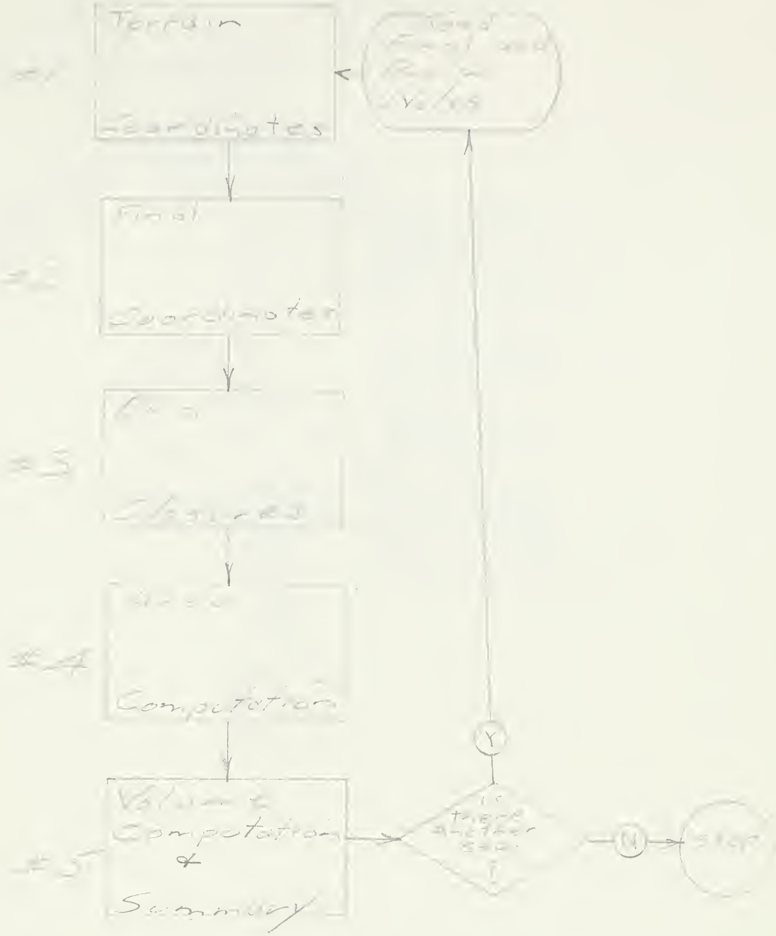
# 3 CONTROL DATA

(a) Value of "q" (the maximum vertical distance between the preliminary and the final section).
(b) Chainage equation.
(c) Structure.

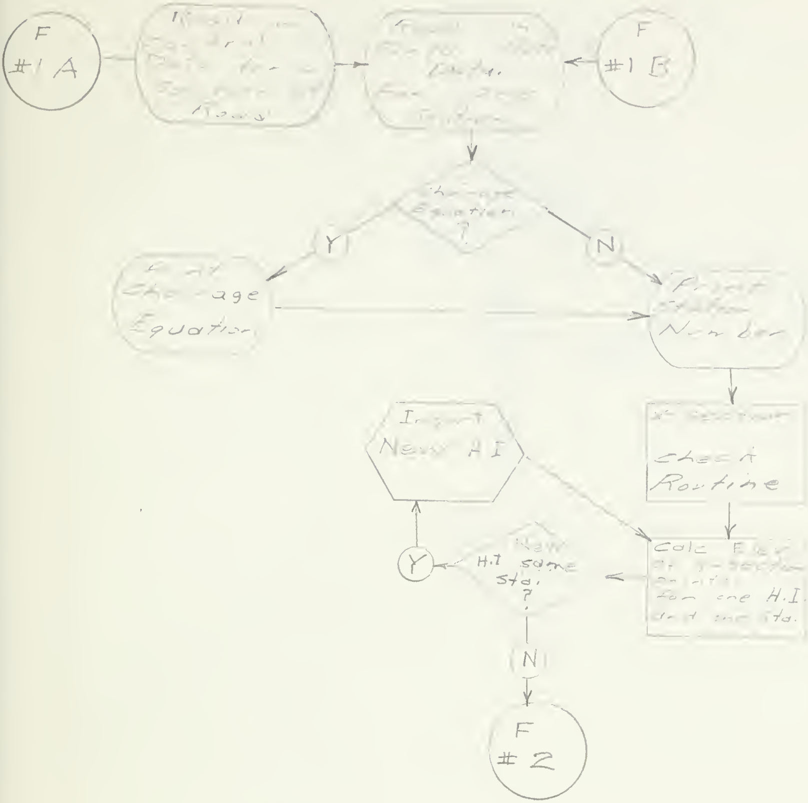
PRINT

1. Station Number.
2. Area of Cut.
3. Area of Fill.
4. Volume of Cut.
5. Volume of Fill.
6. Adjusted Fill.
7. Accumulated Cut.
8. Accumulated Cut Minus Adjusted Fill.
9. Chainage Equation.
10. Structure Omission.

Earth Embankment Computation

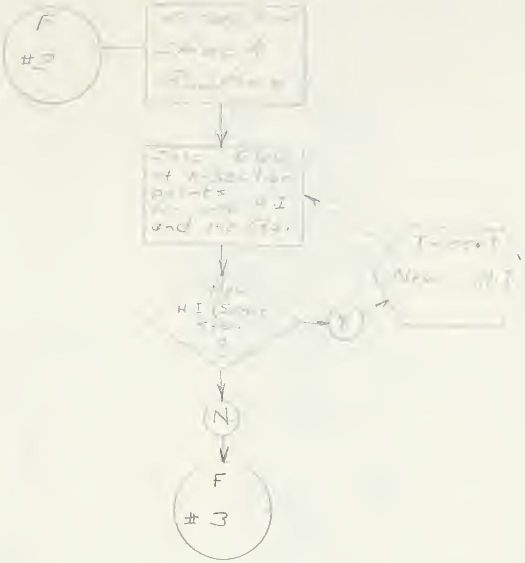


Terrain Coordinates



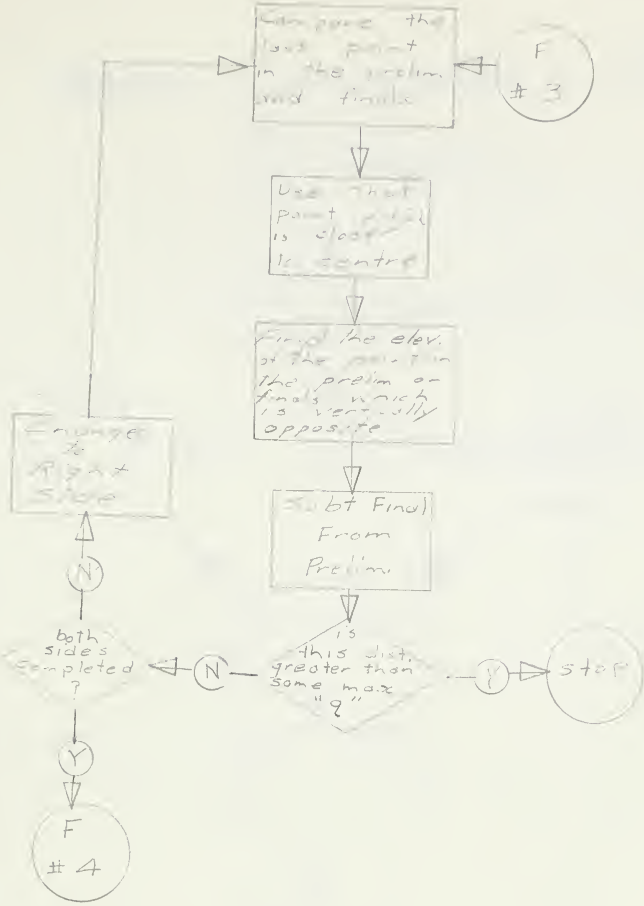
#3

Final Flowchart #3

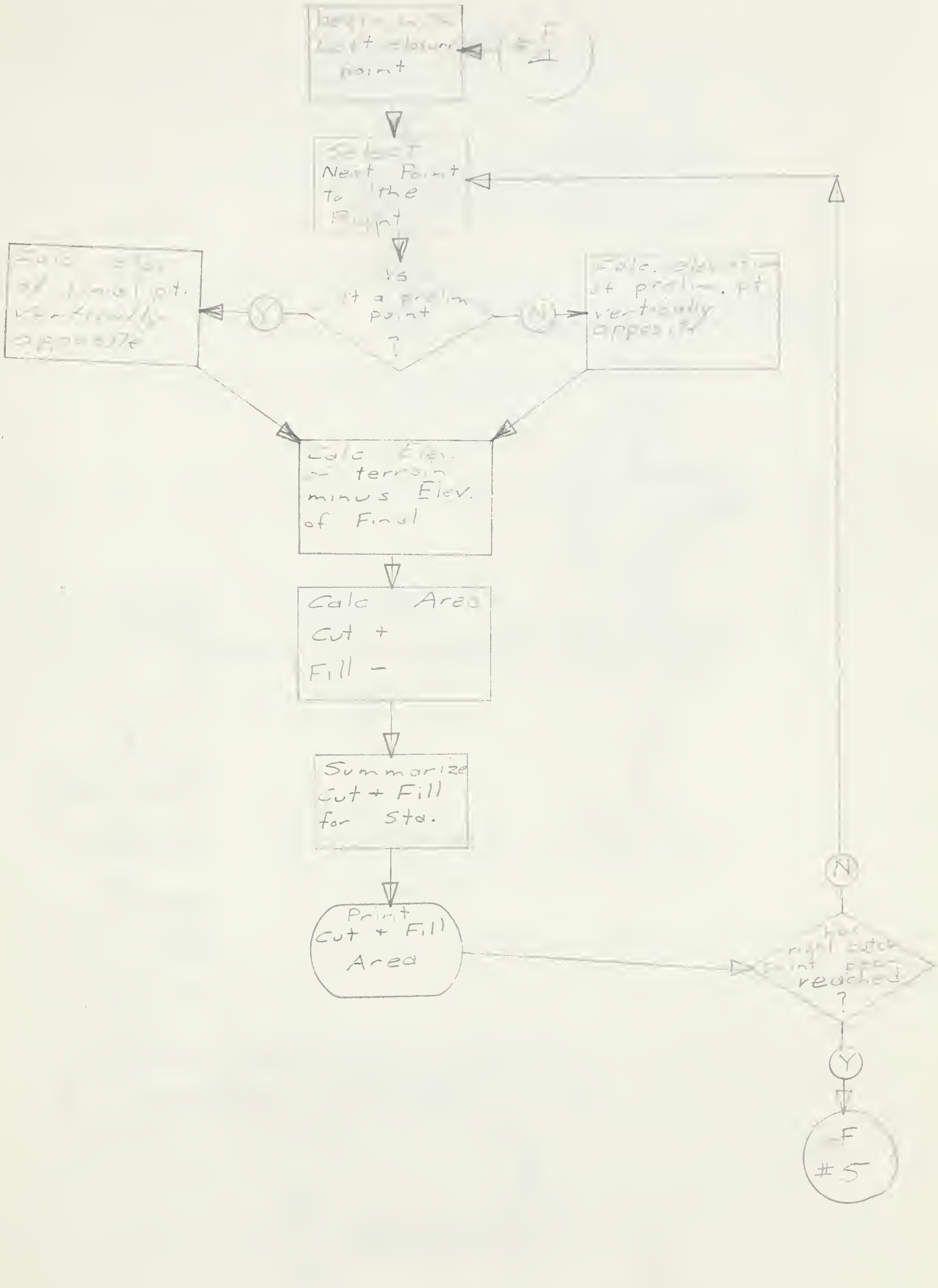


F #3

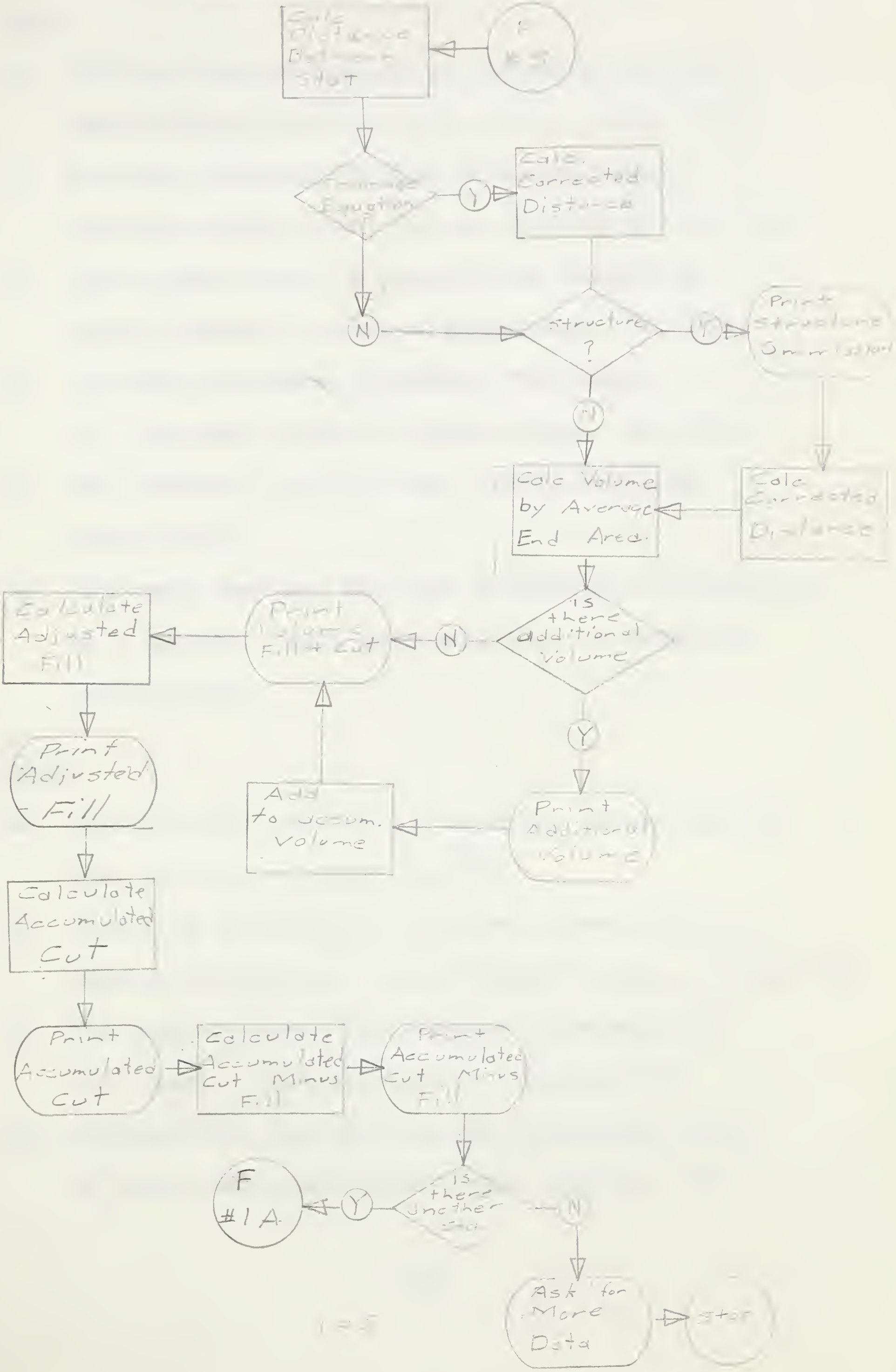
Final Changes


Compare the last point in the prelim and finals
F #3
Use that point which is closer to centre
Find the elev. of the point in the prelim or finals which is vertically opposite
Subt Final From Prelim
is this dist. greater than some max "q"
Y
stop
N
both sides completed ?
Y
F #4
N
Change to Right Side

Area Computation F#4


Begin w/ the Left closure point
F #1
Select Next Point to the Right
Is it a prelim point ?
Y
N
Calc. elev. of final pt. vertically opposite
Calc. elevation of prelim. pt vertically opposite
Calc Elev. of terrain minus Elev. of Final
Calc Area Cut + Fill −
Summarize Cut + Fill for Sta.
Print Cut + Fill Area
Has right catch point been reached ?
N
Y
F #5

Volume Calculations F#5



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— Enoch Needles, Howard, Needles, Tammen and Bergendoff.
— R.K. Breece, California Division of Highways.
— Theodore F. Morf, Illinois Division of Highways.
— Keith Kohler, U.S. Bureau of Public Roads.
— R. Glen Tyden, Arizona State Highway Department.
— E.S. Preston, Ohio Department of Highways.

(b) Discussion on the use of electronic computation in bridge design and bridge geometrics.

— C.A. Marmelstein, Georgia State Highway Department.
— R.C. Vogt, Ibers and Seaman.
— L.R. Schureman, U.S. Bureau of Public Roads.
— Jerry C.L. Change, Richardson, Gordon & Associates.
— Paul Yeager, Washington Department of Highways.
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— W.D. Vanderslice, Missouri State Highway Department.

— L.T. Davidson, Illinois Division of Highways.

— Phillip King, King and Gavaris, New York, New York.

(b) Discussion on the use of electronic computation in bridge design and bridge geometrics.

— Paul E. Yeager, Washington Department of Highways.

— C.A. Marmelstein, Georgia State Highway Department.

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(c) Discussion on the use of electronic computation in traffic studies, traffic simulation, and research analysis.

— Peter J. Caswell, Chicago Area Transportation Study.

— G.E. Brokke, U.S. Bureau of Public Roads.

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— Paul E. Irick, A.A.S.H.O. Road Test.

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— Theodore F. Morf, Illinois Division of Highways.

— Robert J. Jansen, Washington Department of Highways.

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— Ben W. Steele, Oklahoma Department of Highways.

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— J.J. Chang, Richardson, Gordon and Associates, Petersburg, Pennsylvania.

— H.J. Schlitt, Nebraska Department of Roads.

— Peter Gavaris, King and Gavaris, New York, New York.

— J.C. Robbers, Minnesota Department of Highways.

— J. Clarkeson, The Clarkeson Engineering Company Incorporated, Boston, Massechusetts.

— J.L. Hawk, Service Bureau Corporation, New York, New York.

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— E.S. Preston, Photronix Incorporated, Columbus, Ohio.

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